WILDERNESS MANAGEMENT:

HUMAN WASTE & WATER QUALITY

Sign at Pelion Plains

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STATEMENT

I declare that this thesis contains no material which has been accepted for the award of any other higher degree or graduate diploma in any tertiary institution and that, to the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Juliette Brassington

ABSTRACT

Human wastes in wilderness areas have a number of impacts. Many of these impacts relate to inadequate disposal methods which are unable to contain harmful pathogens found in human wastes nor prevent animal contact with them. This situation can lead to contamination of surface waters, thereby posing a public health risk. These issues are compounded by the dramatic rise in visitation to these areas and a lack of research or baseline data from which to make informed management decisions.

A case study was undertaken at Pelion Plains in the Tasmanian World Heritage Area to examine the impact of human waste on water quality. Pelion Plains is a heavily used area, and there is anecdotal evidence linking the area to a number of health related problems. Using the traditional indicator method, Faecal coliform levels taken over five sample occasions ranged from 1-410 (cfu) per 100 mL water and Faecal streptococci levels ranged from 1-420 per 100 mL. Results indicate that the water is not suitable for drinking. Currently no warning is provided advising visitors of a potential health risk associated with the consumption of untreated water.

The faecal sterol method was also used due to its ability to differentiate human and herbivore faecal matter. Results indicated that contamination was herbivore in origin. Due to lack of (antecedent) rain during sampling, however, results were not considered to be truly representative in this study. A limited macroinvertebrate analysis was also undertaken to provide much needed baseline data, which may be useful as a pollution indicator for the detection of long term ecological impacts.

This research has demonstrated that inadequate disposal of human wastes is influencing water quality in a wilderness area, and that associated issues of public health are not being addressed. In particular this research demonstrated that the existing toilets and camping activities at Pelion Plains are implicated in the contamination of surface water which is currently used for drinking.

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CHAPTER 1

Introduction

1.1 INTRODUCTION

A well-recognised and potentially problematic relationship exists between the maintenance of wilderness and pressures to facilitate visitation within these natural environments. In general terms this is referred to as the wilderness paradox, where the presence of people who visit wilderness to gain recreational pleasure represents the major threat to wilderness through their associated impacts (Kirkpatrick 1991:85). Similar situations are also experienced in remote backcountry environments and other natural areas.[1] Human impacts are cumulative and increasing rapidly in response to the unprecedented rise in visitation rates since the 1960s (Cole 1996). The continuation and growth of visitation and associated impacts has critical implications for the management of these areas as it not only threatens their integrity but also the quality of visitor experience (Cole 1996; Martin, McCool and Lucus 1989:623).

The importance of effective management can not be underestimated. Many studies attest to the continued and extensive damage that can occur if visitation is not properly directed (Cole 1990; Hammitt *et al.* 1992; Hawes 1994). There are many obstacles, however, which must be overcome when combining the joint management of people and of the natural environment. Finding a suitable equilibrium between ecological integrity and visitor requirements has become the major challenge facing management agencies today.

This thesis attempts to bridge this gap with relation to one specific, often neglected area - that of human waste management. The impacts relating to inadequate human waste management within wilderness environments have serious and far-reaching consequences. This thesis will examine factors influencing and impacts arising from the

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[1] While the term wilderness is applied throughout this thesis, it is recognised that many of the issues discussed are potentially relevant in a wide range of environments which may be termed backcountry, remote or natural.

disposal of human wastes in wilderness areas, whilst also evaluating a number of methods for assessing these impacts.

1.2 The Growth of Wilderness Visitation

It is often argued that the arrival of a large number of visitors to wilderness areas is, in a broad sense, partly a manifestation of growing community awareness and concern for the environment (Valentine 1992:108; Figgis 1993:8). The growing interest in these areas arguably reflects the emergence of a paradigm shift, where biodiversity conservation and sustainable development issues gained increased attention (Ceballos-Lascurain 1996). With growing environmental awareness, many people began to seek a travel experience contained within, and focused on, a natural setting. Increased participation in wilderness visitation is also inextricably related to technological developments; in particular, advances in the production and marketing of lightweight ergonomic camping equipment. This equipment acts to make wilderness environments safer, more comfortable and therefore more accessible to a larger audience.

Corresponding to these changes has been the demand for increased access to, and the provision of, a wide range of recreational and tourism options within natural environments (Inter-agency Working Party 1997:25). The desire for conservation and pressure for increased access can act as opposing and counterproductive forces if management agencies are forced to base decisions on inadequate information. Management agencies charged with the conservation of wilderness areas are often forced to devise new solutions related to the emergence and implications of these two often-competing and opposing demands.

1.3 Wilderness Management

While the growth in wilderness visitation has fortunately been accompanied by a growing realisation of the necessity for management, it still presents a paradox for many people and is a relatively recent idea (Nash 1973). The management of wilderness areas to both sustain wilderness value and to facilitate visitation remains precarious for many reasons. Tourism can bring many economic and social benefits and experiences, such as foreign exchange and employment in regional areas; however, it may also bring environmental, social and cultural deterioration (Craik 1991:xi; Commonwealth Department of Tourism 1994:5).

It is well established that in the absence of any form of visitor or resource management, ecological disturbances occur even with low levels of use (Cole 1981:86). For example Hawes (1994:17) reports a non-linear use-impact curve for Tasmanian wilderness areas, where low use can cause disproportionately high levels of most types of impact. Furthermore, as more and more people visit wilderness areas, previously unvisited areas become more attractive to those with more experience and a desire to avoid the presence of other people. This situation increases the need for management of areas that previously required minimal attention as they received very few or no visitors. This situation also increases the range of responses that are required by management as new areas are being exposed to new impacts.

Management of 'remoter' areas may also be hindered because baseline ecological information is needed to compare and assess human influences, and to help determine the extent to which wilderness values are being maintained (Hendee, Stankey and Lucus 1978:371; Boo 1990:2). Studies to establish these baseline or natural conditions in wilderness areas have been seriously lacking. This situation creates a major predicament for management agencies. For effective management, agencies must have knowledge of natural conditions as well as their direction and rate of change as dictated by ecological processes. These problems have been compounded by the expeditious upsurge in visitation, so that improvements in wilderness management have not kept abreast with the ever increasing size, diversity and range of challenges offered by visitor activities (Cole 1990:363).

Visitors to wilderness areas are also participating in an ever increasing variety of pursuits such as bushwalking, skiing, snowboarding, mountaineering, rockclimbing, ice-climbing, hunting, fishing, sea kayaking, numerous river-based activities such as rafting, as well as being used for scientific, management or study purposes (Lynch 1996). As the range of these pursuits is broad, so too are the responses required from management to help mitigate impacts. For example, each of these activities require a different approach to human waste management and all too often their differing needs are covered by a limited range of policy instruments.

The methods promoted by these policies often assume an ideal situation that ignores many practical considerations. For example, in high altitude areas the ground is often steep and the soil hard, shallow or covered by snow making disposal particularly troublesome. In glacial areas wastes are often tossed into the nearest crevasse. This may initially remove waste from view but with glacial movement and recession waste may eventually contaminate the nearest water source. Rockclimbers on a long route may defecate on a ledge or into a bag which is then tossed to the ground. Rockclimbers, mountaineers or ice-climbers then, due to the nature of their activities, may not be able to adhere to the given policy.

1.4 Visitor Impact Research

Evidence of concerns over recreational impacts in wilderness areas began to appear in the literature as early as 1913 in the United States, where managers noted problems relating to fire and sanitation (Downing and Clark 1979:18). Despite this early recognition of problems, minimal research was undertaken on the impact of visitation in wilderness areas. In a review of visitor impact research, Cole (1990) concluded that the quality of publications is relatively poor and that large knowledge gaps remain. Cole (1990) avers that, because of such deficiencies in ecological knowledge, management decisions are often based on, and assessed in, aesthetic terms. The majority of studies, he concludes, examine tangible aspects and pay scant regard to what is not immediately visible. Research effort in Tasmania, according to Hawes (1994 vol III:8), suffers a similar fate, as it is largely uncoordinated, inadequate and generally confined to qualitative statements.

While impacts traditionally receiving the most attention are the aesthetic ones (such as track erosion or issues affecting vegetation), issues relating to sanitation remain the most difficult and often neglected (Hawes 1994 vol III:11-18; Parks and Wildlife Service [PWS] 1996). The consequences of this can be disastrous. In the United States, for example, more money is spent mitigating track impacts than on any other form of wilderness impact. At the same time the flagellated protozoan pathogen of the small intestine, *Giardia,* spread to nearly all surface water in wilderness areas (Cole 1985). *Giardia* is now so widespread in the United States and Canada that it is known colloquially as 'backpackers disease' or 'beaver fever'[2] respectively.

[2] The term 'beaver fever' arose in Canada, where beavers became infected with *Giardia.* Once infected, like many other native animals, beavers shed cysts in large numbers in their faeces thereby contaminating surface waters (Yapp 1989:74).

Until approximately 20 years ago, no one in the United States ever considered it unsafe to drink directly from mountain streams (Meyer 1994:15). In 1977 the Sierra Club backpacker's guide touted drinking directly from wilderness waterways as one of the 'very special pleasures of backcountry travel' (Meyer 1994:15). In contrast, it is now widely accepted that no surface water in the United Stated is safe to drink due to the presence of enteric indicator bacteria (Suk, Sorenson and Dileanis 1987:71). Sources of contamination are commonly believed to include human and animal faeces. Clearly inadequate disposal of human wastes has rendered untreated surface waters throughout the entire United States unsafe for consumption (Meyer 1990:285). This lack of effective management has resulted in the loss of one of the 'special pleasures' associated with wilderness travel. While there are several other impacts associated with the inadequate disposal of human wastes in remote areas, such as olfactory and aesthetic aggravation, the transmission of enteric disease remains the most harmful and problematic. Transmission principally occurs through faecal contamination of surface water. Other avenues of transmission include direct human oral contact, or via animals (for example, insects).

Microbiological water contamination from human faeces presents one of the most serious impacts associated with human wastes in wilderness areas. While the remote nature of wilderness areas precludes the provision of certified water sources or common sanitary facilities, adequate alternatives have not always been found. In particular, this is due to the harsh environmental conditions found in some remote wilderness areas. Whilst it is difficult to ascertain the exact impact that humans have on water quality in wilderness areas (because not all water pollution is directly caused by humans), research remains inadequate.

1.5 Research Outline

Visitor impact research in wilderness areas is rudimentary at best. The situation with regards to human waste disposal is particularly poor. Human wastes in wilderness areas remain problematic despite increased visitation rates. Greater research into the sanitary significance and environmental impacts of human wastes in wilderness areas is urgently required.

Research on the impact of human waste disposal requires the integration of a range of traditionally separate areas of knowledge. Current methods and practices for the disposal of human wastes in urban areas often become immediately redundant due to the difficulties that emerge from working in a wilderness area. The sanitary significance, however, remains unchanged. Given this situation, policies surrounding the disposal of human wastes may not be satisfactory and it is possible that serious issues of public health are being ignored.

Throughout many areas of the Tasmanian World Heritage Area (WHA) the toilet systems fail to work successfully. It is often argued that this is due to the harsh environmental conditions. Minimal research has been conducted on the impacts that human wastes might have within the Tasmanian WHA, or on the effectiveness of current disposal policy. The ability of managers to implement effective policies is, therefore, seriously limited due to a lack of baseline data from which to make assessments. This thesis represents an attempt to fill some of the gaps that exist in the knowledge regarding human wastes in the Tasmanian WHA, with particular emphasis on the potential for surface water contamination.

In order to investigate impacts and risks associated with human wastes in the wilderness environment, a case study was undertaken focusing on one site within the Tasmanian WHA. Pelion Plains on the Overland Track was selected as the focus area for detailed investigation. As a preliminary literature review revealed that surface water contamination represents one of the greatest risks from human wastes, this became the focus of the case study investigation. While the research is broadly centred on the process of contamination, finding an appropriate and suitable method of assessment became one of the greatest challenges.

The primary objective for undertaking a case study was to assess the appropriateness and suitability of various methods used for the detection of faecal contamination in surface waters in a remote area. Pelion Plains was selected as a suitable location for undertaking a case study for a number of reasons. Pelion Plains, a high use area within the Tasmanian WHA has a combination of infrastructure, is accessible and has anecdotal evidence of a pre-existing water quality problem.

1.6 AIMS AND HYPOTHESIS

This thesis investigates the hypothesis that human wastes produce a detectable impact at the Pelion Plains region. One aim of this thesis, therefore, is to investigate if any evidence of human waste impacts exists particularly in relation to water quality. This thesis also aims to appraise the traditional method used for assessing human waste impacts on water quality for its use in wilderness environments. The final aim of this thesis is to highlight issues related to the management of human waste in wilderness areas with particular emphasis on public health.

1.7 THESIS OUTLINE

The following chapter of this thesis, Chapter 2, introduces the topic of human wastes, and highlights problems which may be experienced with their *in-situ* disposal in wilderness areas. Environmental conditions influencing biodegradation are considered, as is the effectiveness of toilet systems currently operating in many wilderness areas in containing the pathogenic content of human wastes.

The impact which human wastes may have on surface water quality in wilderness areas is considered in detail in Chapter 3. The management problems associated with water quality are explored, as are factors resulting in consumption of potentially contaminated water. A review of studies that have investigated human use and faecal contamination of surface waters, is provided along with details of the pathogens commonly associated with human wastes.

Chapter 4 introduces the case study used in this thesis, providing a description of the Pelion Plains region of the Tasmanian WHA and an overview of environmental and social factors operating within this area.

Chapter 5 details the investigation of traditional microbiological indicator organisms (Faecal coliforms and Faecal streptococci), which were used to assess the surface water quality of Douglas Creek, the main source of drinking water at Pelion Plains. The findings and the discussion arising from this investigation are explored in detail, as is general information relating to water quality and its management at Pelion Plains and the Tasmanian WHA in general.

Chapter 6 evaluates the usefulness of the traditional method of assessing microbiological water quality as it relates to wilderness areas. Two approaches are investigated for their effectiveness in the management of wilderness water quality, faecal sterols and benthic macroinvertebrates. The results of these two methods are presented and discussed in this chapter with particular emphasis on their applicability for use in wilderness areas.

Chapter 7 draws together the conclusions identified throughout the previous chapters and highlights their significance for the management of human wastes in the wilderness, with particular reference to water quality. Recommendations for areas requiring further research are also outlined.

CHAPTER 2

Human Wastes in Wilderness Areas: Issues and Impacts

2.1 INTRODUCTION

Managing human wastes in wilderness areas remains a difficult and complex problem. In areas both with and without toilet infrastructure, heavy visitation rates have resulted in problems ranging from visual and olfactory aggravation to serious issues of public health. Furthermore, the provision of infrastructure to address these problems has the potential to alter the wilderness values deemed important in these areas. Due to the ongoing rise in visitor numbers the management of human wastes has therefore emerged as an issue requiring the urgent attention of wilderness managers.

The aim of this chapter is to examine *in-situ* human waste disposal in wilderness environments and some of the problems associated with it.[3] This chapter outlines the composition of human wastes and explores the many obstacles that may prevent successful disposal of wastes in wilderness areas. This will include an examination of environmental and social conditions that are required for successful decomposition of human wastes, and a brief outline of why specific toilet systems might not be effective under particular environmental conditions. This background information will then be used to explain why faecal pathogens may be transported and contacted by humans and animals in these areas.

2.2 PROBLEMS OF HUMAN WASTE DISPOSAL

To understand the difficulties involved in human waste management in wilderness environments, it is necessary to consider many interrelated factors including: the

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[3] This examination is principally based on a review of available literature. It incorporates personal observations and communication with a wide variety of wilderness visitors arising from both this study and two years spent working as a guide on the Overland Track. It also includes information gained from participating in a variety of pursuits in natural environments over a ten-year period.

composition of human wastes; environmental influences on the decomposition of that waste and; the movement of pathogens through soil.

Human wastes are deposited in wilderness areas in a number of forms including faecal, urine and menstrual wastes. Each of these may be harmful in varying forms for reasons discussed below.

2.2.1 The Composition of Human Waste

2.2.1.1 Faecal Wastes

Humans excrete on average between 100-400 grams (wet weight) of faeces per day (Bitton 1994:140). Human faecal waste includes organic matter as undigested or transformed foodstuffs, various compounds containing nitrogen, phosphorous (as P_2O_5), potassium (as K_2O), calcium (as CaO), carbon, and a number of pathogenic and non-pathogenic organisms. The bacterial content of faeces represents approximately nine per cent of the wet weight (Bitton 1994:140).

The pathogenic content of faecal matter is potentially dangerous if other animals or humans come into contact with it. Pathogens are disease causing organisms and those present in human faeces include bacteria, viruses, protozoa and helminths (Crennan 1992:14). Some of these pathogens are a hazard to public health (Geldreich 1966:1). Human waste also contains non-pathogenic organisms. The high nutrient content of faecal excrement in the natural environment may also artificially raise nutrient levels, having deleterious effects on local native plants encouraging invasion by exotic species (Smith 1990:2). A number of potential consequences of exposure to faecal wastes in wilderness environments will be discussed in detail in Chapter 3.

2.2.1.2 Environmental Influences on the Decomposition of Faecal Waste

Biodegradation (the breaking down of organic compounds by microorganisms) remains the most effective means of eliminating the capacity of most organic materials and compounds to pollute the environment (Fuller and Warwick 1985:24). Biodegradation therefore represents the chief rationale behind *in-situ* waste disposal in wilderness areas. Other factors include aesthetics, public health, and the reduction of environmental impacts.

Numerous methods are employed by managers to facilitate biodegradation. The various impacts or benefits of these approaches are discussed later in this chapter. Firstly, however, it is important to understand the decomposition process itself, examine the implications of this process, and why it may fail to operate successfully in wilderness areas.

Rapid aerobic decomposition occurs when oxygen can reach wastes and beneficial soil organisms can compete vigorously with faecal pathogens. In a compost pile (such as in a composting toilet), supplying additional organic matter and controlling pile moisture levels stimulates the aerobic decomposition process. During aerobic decomposition, the metabolic activity of soil organisms becomes rapid and generates significant heat (Plumley and Leonard 1981:19). The end product of this process (under suitable conditions) is a pathogen-free humus-like substance. Various authors (Plumley and Leonard 1981:19; Fuller and Warwick 1985:27; Lynch 1996:12) state that aerobic decomposition depends on a number of favourable conditions which also determine the rate of decomposition:

1. temperature (cold inhibits decomposition);
2. moisture of the soil or surrounding medium (high moisture favours pathogen growth and retards oxidation of organic waste);
3. nutrient status of soil (high carbon/nitrogen ratio in soil promotes the growth of beneficial organisms thereby inhibiting pathogen growth);
4. the abundance of other beneficial organisms able to out-compete faecal pathogens;
5. filterability or percolation rates;
5. slope of the terrain;
6. general exposure to environmental conditions; and
7. insect habitation.

Optimum moisture levels for maximum biodigestion occur where the amount of water occupying the soil channel walls and pore space does not interfere with soil oxygen exchange with the atmosphere (Fuller and Warwick 1985:26). If the soil is waterlogged (either at the surface or some depth below), oxygen, which is essential for aerobic respiration of soil microorganisms, will diffuse through the water at a slow rate. Under these conditions oxygen will be in short supply, and anaerobic conditions will determine the decomposition process (Liddle 1997:206).

Pathogenic destruction occurs through competition between pathogens and other biological organisms. Under anaerobic conditions, however, when the anaerobic and facultative anaerobes dominate, decomposition slows down. In these circumstances pathogens remain viable for a longer time and it may take two years or longer for decomposition to completely occur. Viruses can retain their infectivity and survive in soil for up to six months without significant interference from existing soil micro-flora. Viruses will also survive better at lower rather than higher temperatures (Bitton 1980 cited in Lynch 1996:12). As camping or hut sites are typically determined by access to a reliable water source, if adequate provisions are not made available for waste disposal or conditions are not suitable for biodegradation, the potential exists for the surrounding water to be contaminated by human faecal products.

2.2.1.3 Urine and Menstrual Waste

Human urine, while containing large amounts of nitrogen, has negligible pathogenic content unless voided by an unwell person (Leonard and Plumley 1978:350). While the nitrogen in urine can artificially raise nutrient levels, the issue is not explored in detail here due to limited management options and its negligible pathogenic content. It is important to note, however, that urine can have a detrimental effect on pit and composting toilets by increasing the moisture content and liquid run-off (O'Loughlin 1988). Trials in Tasmania where people were requested not urinate in these toilets have met with limited success (O'Loughlin 1988).

Menstrual wastes contain blood, mucous and endometrial sheds from the lining of the uterus (Lynch 1996:6). The disposal of menstrual wear poses specific concerns for women in wilderness areas. A New Zealand study, conducted by Lynch (1996), investigates in detail problems associated with menstrual wastes in the backcountry. In this study, Lynch (1996) highlights lack of information as a major problem, noting that waste management literature has not traditionally made the distinction between menstrual waste and general toilet waste.

Many of the chemicals used in menstrual wear are deodorants and organochlorines designed to kill bacteria and other microorganisms. If such articles are buried the chemicals may affect micro-flora in the soil, thus delaying their decomposition. Lynch (1996) notes that using toilets to dispose of wastes is the most common method of disposal where one was available and if not, common practice is to bury wastes in the ground. The disposal of menstrual wastes in toilet systems commonly found in remote areas is not a suitable approach, as they are very slow to decompose and may alter soil micro-flora. There is very limited literature dealing with this issue and in that which does, visitors are advised to carry out all menstrual waste products, except in grizzly bear country (Meyer 1994). It appears that some women, however, do not view this approach as appropriate (Lynch 1996:23-24). The report by Lynch (1996) concludes that there is a real lack of information available to women on the environmental impacts of menstrual waste, on alternative behaviours which reduce those impacts, or on ways to make it more appealing to carry wastes out (Lynch 1996:30). Problems will only get worse as more and more women are visiting wilderness areas (Lynch 1996:27).

2.2.2 Social Considerations of Human Waste Disposal

Faecal matter represents an inevitable by-product of human life. Issues relating to its disposal in wilderness areas are compounded by the fact that in the western world we generally take for granted access to appropriate sanitation infrastructure. Wilderness areas, however, by their very nature and remoteness, preclude access to this infrastructure and to the sanitation experiences of home.

Inadequate disposal of human wastes not only has many ecological side effects and public health implications, it also presents a social impact to visitors by corrupting their wilderness experience. The sight of human excrement or toilet paper reflects the lack of care someone else has taken and highlights their presence, thereby diminishing feelings of being in an area of high environmental quality and remoteness. For all the reasons discussed above, problems of adequately disposing of human wastes in remote wilderness areas remain one of the most perplexing issues facing conservation and management agencies today (Office of National Tourism 1996:10).

2.3 Management Practices

Several toilet systems and approaches to human waste management exist throughout the world, all operating with varying degrees of success. From about the 1980s onwards attempts have been made to treat and compost wastes *in-situ* in areas deemed suitable for infrastructure. These attempts have met with limited success. The more common approaches and techniques, and those that are in place in Tasmania, will now be discussed in more detail.

2.3.1 AREAS WITH NO OR UNUSABLE TOILET FACILITIES

In wilderness areas, toilets can be flyblown, full and unusable or not present. In these situations, guidelines exist for the appropriate disposal of faecal wastes. In Australia it is recommended that a lightweight hand-trowel be used to bury wastes (including toilet paper) 15 cm deep within the soil's organic layer, 100 metres from watercourses or campsites. The rationale for this method is founded on concerns for sanitation and aesthetics (O'Loughlin 1988:48).

Shallow-burial information is generally disseminated through education campaigns such as the Minimal Impact Bushwalking (MIB) campaign in Tasmania, or the Leave-No-Trace campaign in the United States. These campaigns, however, are limited in scope, as they are specifically targeted to bushwalking as indicated earlier (Chapter 1, section 1.3).

The need for privacy is another practical consideration reducing the likelihood of compliance. Visitors may head for an area with adequate cover rather than considering distance from water or camp. Expediency may also override the desire to be consistent with minimal impact principles if a rapid response is required (O'Loughlin 1988:47). In certain weather the impetus to travel 100 metres may dwindle or the nature of the terrain may prevent compliance. Furthermore, trowels can be forgotten, lost or broken and some visitors may not believe that the advised method is correct and do whatever they think is more appropriate.

Research conducted in Tasmania in 1986 indicates that 37.9 per cent of walkers covered wastes with rocks, leaves or twigs. In the same year (1986) an unusually high number, around 25 per cent, of visitors on the Overland Track in the Tasmanian Wilderness WHA contracted gastroenteritis (O'Loughlin 1988:47-48). The next year (1987), after the introduction of the MIB campaign, saw the incidence of gastroenteritis drop to around eight per cent. This reduction has been largely attributed to an increasing connection being made by visitors between what they do with their wastes and whether they get sick (O'Loughlin 1988:vii and 47-48). This suggests that increasing awareness of the dangers posed by faecal exposure heightened visitor awareness of waste disposal issues and may have acted to change hygiene habits in areas without toilets.

Another method that has recently been developed is the *smearing* technique. This method is only recommended for alpine or arid environments which receive minimal visitation, where burial is inappropriate or impossible. The technique involves smearing the waste in a thin layer on a rock. A faeces dry, the sun's ultra-violet rays destroy harmful pathogens and when dry the faecal matter is blown away (Toplis 1994:16). Recently, questions have been raised about the aesthetic and ecological impacts of this approach. Research on the impacts and appropriateness of smearing is continuing in the United States over the summers of 1999-2000 (Ells pers. comm. 1998).

2.3.1.1 The Carry-Out Campaign

While the concept of human waste removal was originally conceived to reduce the impacts of river rafters (where it has received considerable acceptance), adoption by other forms of recreation has been slow (for a detailed discussion see Meyer 1994; Lewis 1997, Nickel 1997). The Australian Wilderness Society advises wilderness visitors to remove *all* their wastes, including excrement, toilet paper and menstrual wear. The total removal method can greatly reduce impacts in sensitive areas. In some areas, particularly alpine environments, soils are shallow and digging a small personnel burial hole destroys root systems of slow growing flora.

One of the primary obstacles preventing the success of total removal is the lack of appropriate technology that could alter peoples' perceptions regarding this practice (Lynch 1996:13). This lack of suitable technology ensures that total removal remains unpopular due to the risks involved in handling and transporting human wastes. Further factors impeding the success of a removal system include a lack of education and management attention (Lynch 1996:13).

2.3.1.2 Shallow-Burial of Faeces: an Assessment

While shallow-burial is the recommended method of human waste disposal in areas with no toilet facilities, as discussed above, limited research exists with which to estimate the potential health and environmental hazards caused by this practice in wilderness environments. There have been many studies on the survival of intestinal bacteria, including some virulent pathogens in soil (Temple, Camper and Lucus 1982:357). This information, however, has generally been gleaned from studies on agricultural soils which have microbial populations distinct from those soils commonly found in wilderness areas (Temple, Camper and McFeters 1980:794). The advice disseminated to wilderness visitors may therefore be based on untested assumptions of soil ecology. For example there is a serious paucity of research on optimal defecation distance from water or campsites.

Under good composting conditions, mixing faeces with certain soil types promotes rapid growth of soil microbes and alien organisms disappear over time (Temple, Camper and Lucus 1982:357). The method recommended by the MIB campaign, however, does not prescribe the mixing of soils and faeces. Faeces are simply deposited in a shallow hole and covered with a thin layer of soil. 'If a disposal method could be devised that mixed soil and feces, then the usual complex of composting reactions should result in a more rapid decline of the intestinal organisms [*sic*]' (Temple, Camper and Lucus 1982:358).

Temple, Camper and McFeters (1980:794) conducted a notable study to test the hypothesis that 'enteric bacteria disappear rapidly after shallow-burial of feces [*sic*]'. The study was conducted over a 51-week period in a high mountainous area and included sites with organic soils and a matrix of vegetation types. The most important finding was that *Escherichia coli* and *Salmonella typhimurium* survived in appreciable numbers for the entire season during which the area was available for recreational hiking (Temple, Camper and McFeters 1980:796). The depth of burial (between 5 and 20 cm) had no effect on the persistence of enteric bacteria and differences recorded among the sites were minor. The absence of inter-site differences indicates that survival may be general, although it is quite possible that warmer or wetter sites produce different survival patterns and rates (Temple, Camper and McFeters 1980:796).

Temple, Camper and McFeters (1980) conclude that it is unrealistic to hope for a rapid die-off of intestinal bacteria when the shallow-burial method is used, and state that for some intestinal viruses, survival times longer than 51 weeks must be anticipated. The authors also warn that the presence of intestinal pathogens at some wilderness sites may become a health hazard in the future. Several other authors commenting on human excrement in wilderness areas conclude that the time required for decomposition of buried human excrement and deactivation of associated bacteria, even under the best conditions, is generally more than one year (Cole 1989; Meyer 1994; Lynch 1996:12).

The recommendation of shallow-burial as the best method for faecal disposal in remote areas is not supported by the studies discussed above. Shallow-burial is, however, considered preferable to surface disposal. While surface disposal renders faeces available for drying, which in turn accelerates bacterial destruction, it is considered aesthetically objectionable and can present significant health hazards. For example surface disposal increases the likelihood of insect transmission of disease and of the contamination of surrounding water sources. Issues of water contamination are discussed in detail in Chapter 3.

2.3.2 Toilets in Wilderness Areas

In sensitive remote areas, toilets may be installed to help overcome problems associated with concentrated visitor presence. It is important to note, however, that the provision of toilets does not guarantee environmental quality, as toilets may be under-maintained, inadequate or inappropriately designed. Some visitors for example, find toilets inconvenient, unhygienic, or too malodorous to use. Given these circumstances visitors act as if there is no toilet, defeating the initial rationale for provision: environmental impact reduction. There are a variety of toilet systems available, ranging from the simple pit toilet (anaerobic) to the newer composting varieties (aerobic).

Pit toilets require minimal maintenance but fail to eliminate odour, or to compost or treat wastes. A pit toilet is simply a hole in the ground with a toilet pan and building on top. When full, lime is added and the pit is then covered with soil and another hole dug nearby. Whilst this is a relatively inexpensive form of waste management, it is far from ideal. As wastes remain untreated the potential exists for the dispersal of harmful bacteria, viruses and protozoan into the surrounding environment. Foul odours associated with intermediate sulphur compounds are always produced in an anaerobic process such as in a pit toilet (Plumley and Leonard 1981:19). This not only attracts large quantities of flies, but can greatly reduce the likelihood of visitors actually using a toilet as it is deemed too malodorous.

Pit toilet systems, which are common in Tasmania, are often dug down to the bedrock. The restriction of soil drainage by an impermeable layer of soil or bedrock can lead to saturated flow conditions in a zone at, and just above, the contact between the permeable soil and the impermeable material.

A study on the movement of bacteria and nutrients from pit toilets in the United States found that when only a thin mantle of soil existed over bedrock there was a good chance that micro-organisms were being transported to surface waters (Nichols, Prettyman and Gross 1983:179). Bacteria from sewage in pit toilets were recorded from three to 70 metres from the source (Nichols, Prettyman and Gross 1983:172). In another investigation King and Mace (1974:2457), concluded that the most likely source of coliform bacteria in surface waters was from effluent from the common pit toilet on each site investigated. One reason for this is that shallow soils with underlying bedrock do not impede seepage appreciably (King and Mace 1974:2457).

It is possible then that a pit toilet may not prevent the transmission of pathogens into the environment under certain environmental conditions. If a pit toilet is available and used, however, it may limit the numbers of personal burial-holes being dug in a concentrated area. While pit toilets may also superficially limit animal contact with human faecal matter, animals are still able to dig into and around the pit as no effective barrier is provided.

While several alternative systems have been employed in various wilderness areas, many have proved incompatible in harsh environmental conditions - especially those in wet and cold areas.

A large number of different composting toilets are available worldwide, although the basic concepts are similar. Models include: the Phoenix; Skagit; Clivus Multrum; Cage Batch system and the Rota-Loo (Crennan 1992). Dehydration toilets trialled throughout the United States include the Shasta Waterless Toilet and a prototype called the Rocky Mountain Toilet. All of these systems have proven incapable of achieving successful operation in cold and wet environments. One of the main problems with all composting toilet varieties is their inability to deal with effluent that leaches through the pile, and which may then enter surface waters.

Developments have also been made into using solar energy to assist in composting. One of the first of this kind was the Mount Whitney Solar toilet which proved expensive to install. More recent attempts at using solar energy have been employed in Yosemite National Park (Lachapelle, Land and Clark 1997) and the Muir Snowfield at Mount Rainier in the United States (Ells 1997). The high cost of solar toilets and the ongoing maintenance requirements, however, prohibits their use in most wilderness areas.

As suggested by the name, fly-out holding tanks hold the untreated waste *in-situ*. When full, the unit is sealed and removed by helicopter for treatment and disposal. While this system prevents any possibility of harmful pathogens entering the environment there is a limit on usage, the system can become malodorous and they are expensive to service. The major benefit of holding tanks is that as long as visitors use them, there is no chance of environmental contamination from human wastes. They also require minimal maintenance and are relatively cheap to make. The likelihood of animals contacting the faecal wastes is also eliminated as is handling of human wastes by management staff. Wastes can be directly treated and disposed of by appropriate agencies trained in the handling of hazardous wastes.

Many of the above mentioned systems require the use of helicopters to remove wastes from remote areas. However, both the cost and the impact on the wilderness experience of visitors limit the use of helicopters. Use of helicopters in a non-peak time, however, can minimise the impact on visitors and maximise their cost effectiveness as at the end of the seasonal peak toilets are generally at their fullest. Removal at the end of each season also ensures that wastes are not left *in-situ* for the non-peak period, which generally is cold, wet, or both thereby decreasing chances of surface water contamination.

2.4 CONCLUSIONS

If faecal wastes remain untreated in the environment, and if human and animal contact with this waste is possible, then issues of public health are not being adequately addressed. Clearly, more research is required to help find solutions which prevent human excrement from leaching into surface waters. The effectiveness of the current precaution of burial in areas without toilets remains largely untested, and some toilet designs are neither adequately maintained nor suitable. Whilst conditions will clearly not always be ideal for the biodegradation of faecal wastes, the limited amount of information on the subject compounds the difficulty of making informed management decisions.

Issues relating to the disposal of menstrual wastes are also largely ignored by management agencies and current literature, creating a situation where appropriate disposal information is largely unavailable. This chapter suggests the urgent need to expand both the research on, and outlook of, appropriate disposal methods, and highlights the importance of education for visitors to these areas. The current situation clearly does not adequately contain the pathogenic content of human faecal matter or stop it from entering the surrounding environment. This has serious implications for both ecological and public health. It is to the potential impacts that the pathogens present in faecal matter may have in wilderness environments that this thesis will now turn.

CHAPTER 3

Wilderness Water Microbiology

3.1 INTRODUCTION

Most remaining high-quality water found today occurs near the headwater of river systems. These areas are also commonly valued for their recreation potential. Frequently an assumption is made that these surface waters are safe for untreated consumption due to the remote or 'pristine' nature of the surrounding environment. There is much evidence both anecdotal and scientific, to suggest that this is not the case. A study by Fair and Morrison as early as 1967 concluded that even supposedly high quality mountain stream water may be a potential source of waterborne disease transmission due to faecal contamination.

With increasing visitation to wilderness environments, issues relating to water quality will be exacerbated (Gustafson and Dille 1986). This chapter will explore a number of the problems associated with this particular type of impact. It will also highlight reasons why it may have been disregarded as a management issue, such as lack of information and suitable technology.

Initially this chapter will examine management issues surrounding water quality in wilderness environments, and reasons why visitors may consume contaminated water. It will then analyse the limited literature that is available on this topic, whilst outlining problems associated with these studies. Finally, this chapter will explore the most common pathogens that are, or might be found, in wilderness surface waters and further emphasise the need for increased attention to this area.

3.2 MANAGEMENT PROBLEMS

Deteriorating water quality in wilderness areas creates a number of difficult problems for managers. Important barriers to improved management of faecal contamination include insufficient research and lack of monitoring, poor communication among managers, poorly defined objectives and inadequate technology (Cole 1985:138). Most evidence of decline in water quality remains anecdotal or limited due to the lack of comparative data which is itself largely due to difficulties relating to remoteness and the deficit of field testing procedures. Often the cost, time and logistics involved in testing render water quality assessments and monitoring in remote areas a low priority for managers (Tunnicliff and Brickler 1984:909). However, this forms only part of the problem.

As there is a real lack of baseline or monitoring data, it is often impossible to determine the full extent or water contamination or assess any deterioration of surface water quality (Cole 1990:361; Yapp 1989:69). While lack of assessment information and evidence of declining water quality was highlighted in the United States as early as 1979, United States management agencies and others with similar visitor, environmental and recreational patterns, failed to record basic water quality information (Silverman and Erman 1979:73).

A compounding issue for management is the lack of information regarding visitor morbidity. This information is often achieved anecdotally due to difficulties in gathering this kind of epidemiological information. Doctors tend to treat patients with gastrointestinal upsets empirically due to high costs involved in pathological testing. This means that the causative agent of these diseases often remains unknown, as many enteric diseases present similar symptoms and may be treated with a 'blanket' medication. Wilderness visitors are often transient and delays in the outbreak of symptoms mean difficulties arise in accurately placing the actual site of contamination. The problem is compounded as visitors often seek medical advice a long way from the site of contamination. Certain individuals may also fail to seek medical advice for gastrointestinal problems, believing it does not warrant a doctor's visit. To better understand these problems, epidemiological studies of visitors to wilderness areas should, according to Yapp and Wade (1989:7), acquire a high priority.

Another major obstacle limiting effective management of water quality arises due to problems of accurately locating the source of water contamination, as both human and animal excrement may be washed into surface waters when it rains. Difficulties arise in differentiating these sources. Drinking water, for example, is usually subjected to tests for microbial indicators (ANZECC 1992:4-5). The microbial quality of water is generally assessed by determining the incidence of various indicator bacteria. The coliform group (aerobic and facultative anaerobic, gram negative, non-spore-forming, rod-shaped bacteria) and Faecal streptococci are the most frequently used indicator bacteria to assess the sanitary quality of water. Presence of these bacteria indicates recent faecal contamination. These methods are not only complex, difficult and costly (ANZECC 1992:1-5), but they fail to differentiate between human and other animal excremental pollution. Common indicators, while verifying faecal contamination, are unable to adequately locate the source. The inability to locate the actual source of contamination inhibits management decisions with regards to water quality issues (this issue is discussed further in Chapter 6, section 6.2).

Management difficulties are further augmented by problems including: how to assess the risk to visitors and the danger to acute casualties in remote areas; how to determine the distribution of contamination and its impact; and the potential build-up of a reservoir of infection in native wildlife. Concern must also be given to the legal responsibility management has to visitors and the implications surrounding the problem of issuing or not issuing a health warning (Yapp 1989:69).

Whilst managers are on one side charged with conservation or protection, another aspect of their role includes protection of people (Yapp 1989:69). Each of these factors discussed above combine to make decision making and effective management of wilderness water quality a difficult, complex and challenging problem.

3.3 Why Do Visitors Consume Contaminated Raw Water?

Visitors to wilderness areas drink raw water for a variety of reasons. Warnings may not be given by the responsible management agency because they have no method for assessing the quality of water. The education campaign may not reach some visitors until it is too late and they arrive for a trip unprepared for water treatment. Visitors may not give credence to warnings as they personally have visited an area many times but have never been ill. Managers may be reluctant to give warnings because they personally drink the water without recognising any ill effect (perhaps because they have developed immunity, which other visitors may not have). A health warning may be perceived to infer that an area is not as 'pristine' as expected so that managers may not provide one for fear of deterring visitors or creating the wrong impression. Visitors may not own or have access to a water purification devise and therefore not carry one. Consumption may occur inadvertently when swimming or crossing a river. People may believe an area along the trail away from a hut or camp to be safe when it is not. There are therefore many reasons why visitors to wilderness areas may drink raw water believing it to be safe. The following section will now examine studies that have investigated the relationship between human use and levels of faecal contamination in surface waters. The implications of these findings will provide important considerations for the management of wilderness water quality.

3.4 A Review of Studies Investigating Human Use and Faecal Contamination of Surface Waters

There is a limited amount of literature concerning water quality within wilderness areas that examine the relationship between bacterial content and human use. Of those that do exist, the vast majority have been conducted within the United States with limited research available from other countries. This is surprising given the recreational and visitation semblance between the United States and other areas, and widespread evidence of problems in those areas.

3.4.1 Findings with no Connection Between Visitation and Faecal Contamination

Lee, Symons and Robeck (1970), in a detailed investigation of a remote high elevation watershed, analysed the effect of three different human use levels on water quality. They found no measurable influence could be determined on bacterial indicator population densities because of the increase in human use level (though enteric pathogens were found in remote sampling stations). They did, however, recommend that watersheds with higher human use levels should be studied to determine at what use level influences might occur.

Carswell, Symons and Robeck (1969) upon reviewing five different studies concluded that little or no deterioration in bacterial water quality occurred when recreation was permitted in a watershed. According to Christensen *et al.* (1978:108) other studies have also demonstrated little or no influence on water quality from human use, including Skinner *et al.* (1974). Rosebery (1964), in a 1958-60 study of recreational use in a municipal water supply in Missouri, concluded that high recreational usage was not reflected by a proportional increase in bacterial counts. They did find, however, that the site with the greatest recreational activity had the highest mean count of bacteria in 1958.

In a study that is often cited to claim that recreation does not affect water quality, Stuart *et al.* (1971) found that a watershed closed to public entry since 1917 yielded water with four to six times the coliform count found in an adjacent mountain watershed open to recreational activities. The authors postulate that 'human activity' coincided with an unexpected lower bacterial count and that a rethink on water standards was necessary as a result. However, it must be emphasised that 'human activities' in this study include logging, which undoubtedly will drive from the watershed any wild animal populations that would contribute to the bacterial pollution.

In a more recent study, Ells (1997) found little evidence of Faecal coliforms, Faecal streptococci or enterococci in run-off along the most frequently used ascent route to the summit of Mount Rainier, which sees up to 10 000 people attempt to reach the summit per year. During this five-week sampling, no faecal microorganisms were found in the run-off. However, computer modeling of the predicted flow paths of run-off completed after the fieldwork indicated that the main areas of run-off might be hydro-geologically different from the areas that were sampled (Ells 1997).

While none of these investigations find a direct correlation between human use and faecal microorganisms, there are a number of issues with the studies that must be examined. All, with the exception of Ells (1997), fail to include the possibility of precipitation or run-off as an influence on bacterial counts, or to recognise the role of sediment in trapping microorganisms.

One study which did consider the implication of precipitation is that by Silverman and Erman (1979). They investigated alpine lakes in the Kings Canyon National Park in California to ascertain baseline conditions and potential visitor effects. They found signs of increased bacteria concentration after precipitation and concluded that water is generally safe for consumption except immediately after rain.

3.4.2 Studies With a Connection Between Visitation and Faecal Contamination

In contrast to the investigations detailed above, there have been numerous studies attesting that human use does influence the microbiological quality of surface water.

Bacteriological examination of water samples from 16 mountain streams in Colorado, located in areas with no permanent human habitation, showed Faecal coliform contamination in each stream. Interestingly, the highest concentration occurring between June and August (500 Faecal coliforms per 100 mL) indicating a seasonal pattern correlating with visitation (Craun 1979:132). The author concludes that human faecal excrement was contaminating the surface waters.

Gustafson and Dille (1986) surveyed drinking water sources for sanitary quality at five backcountry camping sites in the Pisgah National Forest of North Carolina. The disposal of human faecal material was left to the individual where it was usually buried in shallow holes (Gustafson and Dille 1986:245). Faecal coliforms were found to be present in 60 per cent of stream samples and Faecal streptococci in all samples. Results indicate that bacterial contamination was occurring and, although tentative, the authors conclude the contamination source was definitely human on one of the site visits.

Varness, Pacha and Lapen (1978) studied the effect of dispersed recreational activities on the microbiological quality of forest surface water. The area studied received heavy camping but had no sanitary facilities. The authors found that indicator densities increased during weekend human-use periods compared to weekdays. Increases were noted downstream from heavily used camping areas when compared to upstream sites. Diurnal rhythms of indicator densities correlated directly with human activity. The question of rapid entry of faecal matter was raised by the authors, who concluded that bacterial indicators were surviving in sediments underlying the surface waters which are stirred up during periods of human use. The authors concluded that a health hazard existed in the watershed, and that a relationship between increased human use and increased indicator densities exists. Results also indicated a rapid seasonal impact of recreation on water quality (Varness, Pacha and Lapen 1978:102).

Stuart *et al.* (1976) investigated aquatic indicator bacteria from a high alpine zone. They found coliforms and Faecal streptococci in alpine mountain streams and lakes in Grand Teton National Park Wyoming. Again in Wyoming, Skinner *et al.* (1974) investigated the effects of summer use of a mountain watershed on bacterial water quality, and found that concentrations of total coliforms and Faecal coliforms and enterococci varied seasonally, indicating a correlation between human use and increased concentration of coliform bacteria.

Wagenet and Lawrence (1974) investigated a water supply reservoir deemed heavily impacted by recreational use. The study concluded that there was a marked and highly localised recreational effect upon water quality, which was limited to areas of high-density use at peak periods.

Surgenor (1977), in a study initiated by the Appalachian Mountain Club, found minimal amounts of faecal contamination, with the highest levels being recorded at inlets, small streams and lakes. While no effort to disclose the source of contamination was made, the author concludes that human contamination is possible from both inappropriate individual behaviour and from failed waste disposal systems (1977:533).

King and Mace (1974) found recreational use of campsites highly effected coliform bacteria populations between campsites and reference sites. They conclude that effluent from pit toilets was the probable source of the bacteria due to the shallow soils (1974:2459).

Christensen *et al.* (1978), in a two-year study of human use in a dispersed recreation area in Washington, found potential risk exists for unfavourable impacts on the ecology and on user health and enjoyment of the area. The results of this study suggest that human waste disposal does have an effect on water quality. More toilet tissues were observed at the site where increases in bacteria were found. Human waste was also found inadequately buried within eight metres from a water source. The study suggests 'a potential relationship between increased human use and increased densities of bacteria' (Christensen *et al.* 1978:115). The authors also question the ability of bacteria to enter the surface water in the absence of rain at rapid rates and believe that bacteria may be surviving in the sediments and are stirred up by people playing in the water.

3.4.3 Problems with these Studies

For effective management of water quality, accurate information concerning the source of contamination is fundamental. The above studies, while investigating faecal contamination, largely fail to accurately locate the source. Some correlations were made regarding increased or intensive usage and a rise in coliform counts, however, the cause or reasons for this are largely ignored. While some authors suggest that the source of contamination is human, as visitors are stirring up sediments, the original source of faecal pollution in the sediment was not adequately addressed. Therefore it remains unknown if the source of contamination is animal or human. Information of this nature is essential for developing baseline data, however, it offers limited potential for abating the problems because the actual origin of contamination remains allusive. For effective management to occur, conclusive evidence sourcing contamination, its mode and portal of entry, and factors effecting contamination levels are required.

While faecal contamination from human sources is preventable through effective management and education, animal contamination is a more difficult issue. Furthermore, as it is likely that animal excrement will be washed into surface waters, the relationship with precipitation becomes critical. Another important factor, which is largely ignored in the literature, is the importance of animal contact with human excrement. As will be shown in the following section, human faecal pathogens are readily transmissible to other animals, who then become hosts to numerous diseases. While the spread of infection by pathogenic agents depends on factors such as pathogen survival in fresh water, the influence of sunlight and the dose required for establishing infections in particular individuals, widespread distribution does occur (Davies and Evison 1991). Unfortunately, the failure to prevent animal contact with human excrement can have deleterious impacts on the microbiological content of surface waters in wilderness settings.

3.5 Pathogen Transmission in the Wilderness Environment Where the Major Reservoir is Human Faeces

In wilderness areas, both animals and humans consume the same water. If this water is contaminated, both humans and animals can become hosts to certain diseases. The human body acts as a reservoir for numerous pathogens, as do domestic and wild animals (Bitton 1994:78). These pathogens are often shed in the excrement of animals and humans, and may be washed into the surface water. Many animals may act as reservoirs - as living sources or infectious agents - allowing these pathogens to survive and multiply. These diseases are known as 'zoonoses', which now represent approximately 80 per cent of all infectious diseases (Davies 1995:i). As water is consumed in large quantities, it may be infectious even if it contains only a small number of these pathogenic organisms (Brock and Madigan 1988:544).

Human excrement may also be directly consumed by some animals, therefore, any pathogens present in the excrement will also be consumed. These animals may therefore become a reservoir, and pathogens will then be shed in their faeces. When it rains this excrement (containing pathogens) is washed into surface waters, which is then available to humans and other animals to consume. Because of the nature of these environments the spread of disease can occur very rapidly, even into areas that receive very minimal human visitation. Organisms that are pathogenic to humans, and which are transmitted by water, include bacteria, viruses and protozoa. Diseases potentially derived from drinking raw water in a wilderness area will now be discussed in detail.

3.6 Zoonotic Diseases

One of the major factors responsible for the emergence of new zoonoses has been the movement of humans into new geographical or ecological zones (Schwabe 1984). Many of these diseases are associated with occupational and recreational activities, where water is obtained untreated from rivers and creeks (Davies 1995:4).

For the purposes of this study, zoonoses will be classified by the type of aetiological agent: for example, parasitic zoonoses and bacterial zoonoses. Firstly, parasitic zoonoses will be discussed with particular reference to Giardiasis, the world's most common intestinal parasite (Davies 1995:20).

3.6.1 Parasitic Zoonoses

The most problematic parasitic zoonoses present in wilderness environments are the protozoans *Giardia* and *Cryptosporidium*. Discussion will be limited to these two parasites as they are well documented and recognised to occur widely in wilderness areas.

3.6.1.1 Giardia

The connection between untreated human wastes in wilderness areas and the associated health risks, such as *Giardia,* has been well established in both medical and recreational research literature (Brock and Madigan 1988:546). *Giardia* can cause acute illness in humans. It is transmitted via the faecal-oral route and cysts are predominantly acquired via a waterborne source (Craun 1990:268; Steiner, Thielman and Guerrant 1997:335). It is generally accepted from morphological differences that three species exist, *G. agilis* infecting amphibians, *G. muris* infecting rodents and birds and *G. lamblia* (also refereed to as *duodenalis*) infecting a wide variety of mammals including humans (Meyer 1990:284). The spread and transmission of *Giardia* (and other similar pathogens) remains largely unconstrained since a large number of animals have been implicated in the spread of infection, and because visitors typically rely on potentially contaminated raw surface waters for drinking.

Giardia is not a free-living protozoa, and must reproduce in a host. They exist as trophozoites (9-21μm long) and in an ovid cyst stage (8-12μm long and 7-10 μm wide) (Bitton 1994:92). The trophozoites reside in the upper small intestine where they multiply to large numbers and some move down the intestinal tract. Encystation takes place in this downward movement and resistant cysts may then enter water through excremental pollution. An infected individual may shed up to (1-5) X 10^6 cysts per gram faeces (Jakubowski and Hoff 1979).

While water is not a suitable medium for growth of *Giardia*, it has great potential for transmission since only a small number of cysts are required to produce infection (Rendtorff 1954). Analysis by Craun (1979) suggests that only minimal bacterial contamination of streams is required to cause an outbreak of Giardiasis. For example, in Utah (September 1974), 34 campers became infected with Giardiasis after stream samples had mean Faecal coliform counts of 42 per 100 mL (Craun 1979:35). *Giardia* cysts have been found to survive for three months in water at a temperature of 4°C. Hence cold water, once contaminated with *Giardia* cysts, may remain a source of infection for several months (Meyer and Jarroll 1980).

The clinical manifestations of Giardiasis can range from asymptomatic cyst passage to severe malabsorption. Prominent symptoms include frothy diarrhoea, abdominal cramps, fatigue, weight-loss, flatulence, anorexia, and nausea (Craun 1979:127). The onset of acute diarrhoea in a wilderness setting, whilst being uncomfortable for the individual, will dramatically perpetuate the problem if adequate disposal methods are not provided or prove unsuitable.

The data from waterborne outbreaks of Giardiasis in the United States demonstrate that negative results of coliform tests do not provide assurance that the water is free of *Giardia* cysts. *Giardia* cysts have been found in waters that have tested negative for coliforms (Craun 1979:127). The implications of this are discussed in detail in Chapter 6 section 6.2.

3.6.1.1.1 *Examples of Giardiasis in Wilderness Areas*

As humans have encroached on remote environments, they have brought exotic infections and transmitted it to native fauna through faecal contamination. The connection between human travel and the spread of Giardiasis is perhaps clearer than for any other disease. It is precisely this process which renders Giardiasis such a major threat in wilderness environments, as animals concentrations are generally high, diverse and unrestricted.

As early as December 1965 the first waterborne outbreak of *Giardia lamblia* occurred in the United States at Aspen Colorado, where a stream became 'contaminated with *Giardia* cysts from animal sources, hikers or campers' (Craun 1990:269). Over the following five-year period (1976-1981) outbreaks occurred primarily in mountainous areas particularly in New England, the Pacific Northwest, and the Rocky Mountains. Further studies in Washington, Minnesota, New Hampshire, Utah and again in Colorado suggested that drinking untreated water is an important cause of endemic Giardiasis infection in the United States (Craun 1990:271).

Several other United States studies have concluded that the consumption of untreated stream water and the intensity of human use plays a significant role of *Giardia* contamination of surface water in wilderness areas. These include investigations by Craun (1979); Harter, Frost and Jakubowski (1982); Frost *et al.* (1983); Laxter (1985); Suk, Sorenson and Dileanis (1987); and Wallis *et al.* (1996:2789). Recently it has been well established that the parasite is now endemic in all mountainous areas in the United States (Bitton 1994:92).

Surprisingly, the study of Giardiasis in Australia had been neglected until approximately 1985 and there is still very little substantial data on the true prevalence (Boreham, Upcroft and Upcroft 1989:49). The foremost body of work completed in Australia relating Giardiasis to recreation in wilderness areas is a paper by Yapp (1989). This lack of research is astonishing given the extent of problems that have arisen in areas with similar visitor experiences.

The species specificity (or the infectivity) of *Giardia* cysts from animal to humans is not yet entirely clear. However, several investigators have successfully infected a variety of native, domestic and feral animals. This wide distribution indicates that all surface water supplies, no matter how well protected from human activities, may be subjected to contamination with *Giardia.* The degree of significance will depend on the number of infected animals, as well as dilution and die-off (Craun 1990:287).

3.6.1.2 Cryptosporidium

The coccidian protozoan parasite *Cryptosporidium* was first described last century and known to infect a large range of animal species. Human infection was, however, not reported until the 1970s. It belongs to the phylum Apicomplexa which includes other human pathogens such as plasmodia and toxoplasma (Steiner, Thielman and Guerrant. 1997:333). The infective stage of this protozoan is the oocyst (5-7µm) which readily persists under environmental conditions. Following ingestion by a suitable host, the oocyst undergoes excystation and releases infective sporozoites, which parasitise epithelial cells in the host's gastrointestinal tract. The parasite generally causes a profuse and watery diarrhoea that may be associated with weight loss, nausea, vomiting, and low-grade fever. Duration of symptoms depends on immunological status but diarrhoea generally lasts 1-10 days in immunocompetent people and may last up to a month in immunodeficient people (Bitton 1994:97). *Cryptosporidium* oocysts are resistant to disinfection, well able to survive in the acid environment of the stomach and are activated to release their sporozoites upon exposure to bile salts in the small intestine. This combination of factors makes them highly infectious (Steiner, Thielman and Guerrant 1997:333).

Cryptosporidium is a hardy parasite generally transmitted via the zoonotic route involving water. While the prevalence of *Cryptosporidium* in wildlife is not known, it is high enough to maintain a constant supply of oocysts in the United States (Steiner, Thielman and Guerrant 1997:332). The zoonotic route for *Cryptosporidium* is believed to be greater than for *Giardia* (AWWA 1988). These factors make *Cryptosporidium* a greater threat in the wilderness environment than first believed.

3.7 BACTERIAL DISEASES

As human faecal matter may contain up to 10^{12} bacteria per gram, it potentially can transport large quantities of bacterial pathogens to surface waters (Bitton 1994:81). These pathogens traditionally cause enteric infections such as typhoid fever, cholera, and shigellosis. This chapter will now review some of the most important bacterial pathogens potentially found in wilderness areas.

3.7.1 BACTERIAL ZOONOSES

3.7.1.1 *Salmonella* (Typhoid or Paratyphoid fever)

Salmonella are enterobacteriaceae that are widely distributed in the environment and include more than 2 000 serotypes. They can gain entry into surface waters through faecal contamination from native animals. *Salmonella* is the aetiological agent of typhoid, paratyphoid fever and gastroenteritis. While the disease has been brought under control in many countries as a result of the development of adequate water treatment processes, wilderness areas remain vulnerable. This pathogen produces an endotoxin that causes fever, nausea and diarrhoea and it may prove fatal if not treated (Bitton 1994:82).

3.7.1.2 *Campylobacter*

Campylobacter jejuni and less commonly *C. coli* are associated with acute gastroenteritis in humans and may also infect wild and domestic animals (Bitton 1994:83; Davies 1995:37; National Health and Medical Research Council [NHMRC] and Agricultural and Resources Management Council of Australia [ARMCANZ] 1996:2-1). Mountain water streams have been implicated as sources of the infection in Sweden (Metzing 1981). The seasonal occurrence of *Campylobacter* in surface water has also been documented (Carter *et al.* 1987). In-vitro studies have shown that *Campylobacter*, like other bacterial pathogens, may remain viable for months in water obtained from high altitudes kept at 4°C, making it highly viable in many temperate wilderness environments (NHMRC and ARMCANZ 1996:FS-5).

During the summers of 1980 and 1981 *Campylobacter jejuni* was isolated from eight per cent of persons with diarrhoeal diseases acquired in the Grand Teton National Park in Wyoming (Taylor *et al.* 1983). Campylobacter enteritis was found to occur most frequently in young adults who had been hiking in wilderness areas and was significantly associated with drinking untreated surface water in the week before illness. This study by Taylor *et al.* (1983) concluded that *Campylobacter* as well as *Giardia lamblia* should be considered as a cause of diarrhoea in those who have recently returned from wilderness areas. At present there is no endorsed Australian standard method for the detection of *Campylobacter* in waters (NHMRC and ARMCANZ 1996:FS-5).

3.7.1.3 Yersinia enterocolitica

Yersinia enterocolitica cause acute gastroenteritis with invasion of the terminal ileum. Many domestic and wild animals can serve as a reservoir for this pathogen. It is known to thrive at temperatures as low as 4°C and is poorly correlated with traditional indicator bacteria (Bitton 1994:83).

3.7.1.4 Leptospira

Leptospira is a small spirochete that gains access to the host through abrasions of the skin or through the mucous membranes. This pathogen causes leptospirosis (Wiel's disease) leading to infection of kidneys and the central nervous system. It can be transmitted from wildlife to humans consuming waters contaminated with animal wastes (Bitton 1994:84).

3.7.2 Other Bacterial Waterborne Diseases Which are not Zoonoses

3.7.2.1 *Vibrio cholerae* (Cholera)

This gram-negative curved rod bacterium is almost exclusively transmitted by water. Upon release of an enterotoxin it causes mild to profuse diarrhoea, vomiting and a rapid loss of fluids which may cause a sudden death. While rare in the United States, Europe and Australia, this pathogen appears endemic in various areas in Asia. It is also naturally present in the environment (Bitton 1994:82).

3.7.2.2 Shingella

Bacteria of the genus *Shingella* cause bacillary dysentery. *Shingella* spp. have a low infective dose and are highly pathogenic for humans. Characteristic bloody diarrhoea results from the invasion of the colonic mucosa by the bacterium. *Shingella* spp. have no natural hosts other that higher primates, and effectively humans are the only source of infection in the community. The isolation of *Shingella* spp. from waters used for drinking indicates recent human faecal contamination and, in view of the extreme virulence of the organism, is of crucial health significance. While there is a low incidence of the infection in Australia it is much higher among travellers or Australians returning from abroad (NHMRC and ARMCANZ 1996:FS-21).

3.7.2.3 *E. coli*

Several strains of *E. coli* (which affects the gastrointestinal tract) bear virulence factors causing diarrhoea, the major reservoir of this pathogen being human faeces. The average daily load of *E. coli* per person is 1.9 x 10^9 (Jones and White 1984:215) while the infective dose for this pathogen is relatively high, being in the range of 10^6 to 10^9 organisms (Bitton 1994:83). *E. coli* produce a dysentery by a mechanism similar to *Shingella* spp. and the two are so closely related that genetic material can be readily transferred between them (NHMRC and ARMCANZ 1996:FS-9).

Within Australia pathogenic *E. coli* are particularly common in remoter areas, and therefore can potentially contaminate surface water. However, very few studies have been undertaken relating the presence of enterovirulent *E. coli* in consumed water and illness in the community (NHMRC and ARMCANZ 1996:FS-9).

3.8 Viral Pathogens

Approximately 140 types of enteric viruses may contaminate water. These viruses enter the human body orally, multiply in the gastrointestinal tract, and are excreted in large numbers in the faeces of infected individuals. They are responsible for a broad spectrum of diseases that range from skin rash, fever, respiratory infections, and conjunctivitis to gastroenteritis and paralysis. From an epidemiological standpoint, enteric viruses are mainly transmitted by person-to-person contacts, yet they can also be communicated by water transmission either directly via drinking or swimming (Bitton 1994:87). Examples of some human enteric viruses include Hepatitis A, Rotaviruses, Adenoviruses, Astroviruses, Enteroviruses, Poliovirus and Coxsackievirus (Bitton 1994:90).

3.9 Conclusions

In a survey of wilderness managers, Cole (1985:140) found that water pollution was perceived to be a problem in 18 per cent of areas. While this appears minimal, Cole (1985) states that these perceptions may not correspond with the actual severity of impact, but that this figure probably reflects the intensity of management activity designed to mitigate it. This chapter has demonstrated that there is a wide variety of pathogenic agents that are potentially found in wilderness waters. This coupled with the lack of resources allocated to water quality and faecal impacts suggests that issues of associated impacts and public health are largely being ignored.

Statements concerning the appropriateness of using surface water for drinking should be based on the poorest quality water a visitor may encounter (Varness, Pacha and Lapen 1978:103). After precipitation, for example, surface waters may be more heavily contaminated as human and animal excrements are washed into them. More research is required to identify baseline levels and loading fluctuations to establish monitoring regimes able to assess any alteration to water quality, especially in areas where visitation is increasing. This information will assist in ascertaining periods of high risk. More research is also required to accurately identify sources of contamination. Visitor education must be expanded to incorporate information regarding water quality issues so visitors may make informed decisions.

Epidemiological investigations are currently inadequate to assist in the location of problem areas and the exact nature of diseases present. As much evidence of water quality problems remains anecdotal, effective management is restricted. To assist in the mitigation of these problems an expanded education campaign is urgently required.

The following chapter will introduce the case study investigated for this thesis. A water quality investigation was undertaken at a specific, heavily used site within the Tasmanian WHA to ascertain levels of coliform bacteria and to identify problems with current testing methods. The use of a case study will facilitate further investigation of many of the issues raised in the preceding chapters.

CHAPTER 4

Site Description of Pelion Plains

4.1 INTRODUCTION

While chapters 2 and 3 of this thesis explored potential impacts from faecal contamination and associated literature, this chapter now moves on to focus on one particular site within the Tasmanian WHA, Pelion Plains. The use of a case study will facilitate the assessment of the currently accepted method of ascertaining faecal contamination levels, and how this method applied to a remote wilderness area. An assessment of this nature will also provide some basic spatial and temporal faecal contamination information for this area. It is anticipated that information of this nature will be pertinent to the management of other similar wilderness areas.

For the reasons outlined in Chapter 1 (section 1.5), Pelion Plains was selected for investigation. Douglas Creek is situated in the Pelion Plains region of the famous and much patronised Overland Track, which lies within the Cradle Mountain-Lake St Clair National Parks in central western Tasmania (see Figure 4.1).

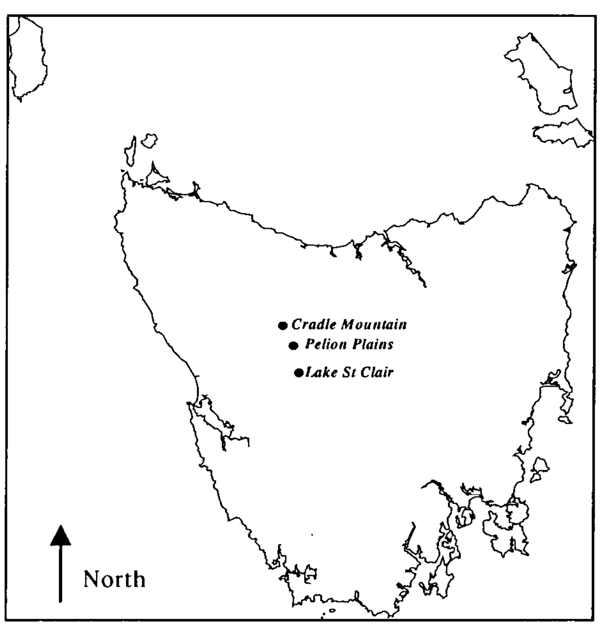

Figure 4.1 Location Map of Cradle Mountain, Pelion Plains and Lake St Clair, Tasmania

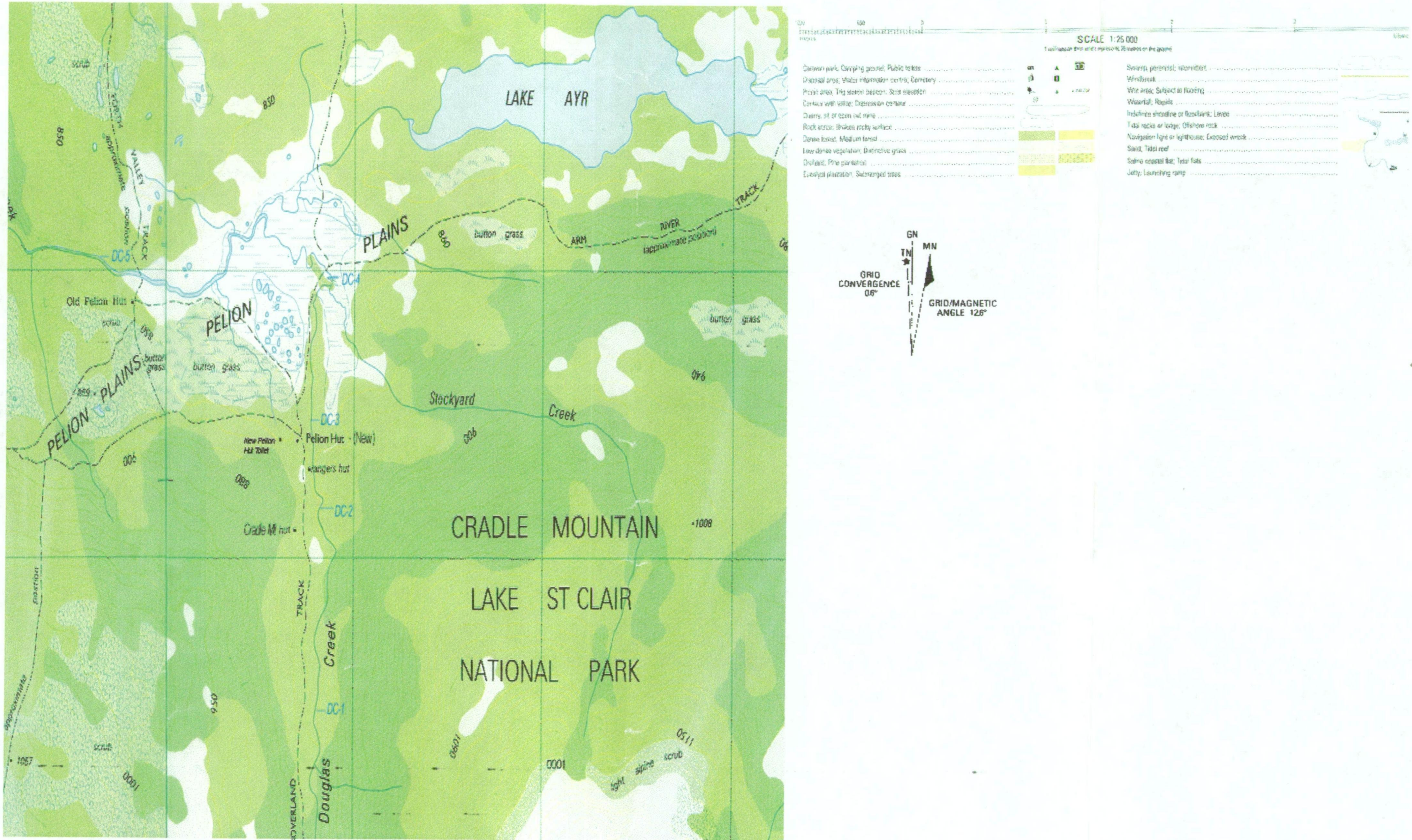

Figure 4.2 The Pelion Plains
Source: TASMAP 1:25000

The Pelion Plains area is also managed as part of the WHA. The rugged mountain peaks and alpine moorlands make this area a popular bushwalking destination with up to 6500 people walking the Overland Track annually. Pelion Plains lie just north of the divide between the Cradle Mountain-Lake St Clair National Parks. Being the halfway point of the Overland Track, and serving as a base for the climb to the summit of Mt Ossa (Tasmania's highest peak at 1617m), ensures that Pelion Plains is one of the most utilised campsites in the WHA. Access to the Plains (see Figure 4.2) is also attained from the east via the Arm River Track, north via the Wolfram Mines track, and the Lees Paddock Track (a variant of the Arm River Track).

Pelion Plains consists of a central grassy plain surrounded by mixed forest types and a ring of mountains including Mt Oakleigh, Mt Pelion East, and Mt Ossa. Douglas Creek originates on the northern slopes of Mt Ossa to the west, and to the east on the northern and western slopes of Mount Pelion East. It then flows through the Douglas Valley and crosses Pelion Plains. Douglas Creek meets the Forth River approximately five kilometres NNW of Pelion Plains, at the southern tip of the Forth Gorge.

4.2 VALUES

Features of outstanding significance in the WHA include: extensively glaciated landscapes; undisturbed habitats of plants and animals that are rare, endangered and/or endemic, representing a rich variety of evolutionary processes; magnificent natural scenery; and an assembly of indigenous sites including cave art. Furthermore, the *Draft Tasmanian Wilderness World Heritage Area Management Plan* (PWS 1997:6) recognises that the area is highly valued for recreation and tourism based on these natural and scenic qualities.

4.3 FAUNA

The Pelion Plains area is home to a large number of animal species. Over 20 species of mammal live in the area including: Bennetts Wallaby (*Macropus rufogriseus*), Pademelon (*Thylogale billardierii*), the Brush and Ringtail Possums (*Trichosurus vulpecula* and *Psuedocheirus peregrinus* respectively), the common wombat (*Vombartus ursinus*), and the Spotted-Tailed and Eastern Quoll (*Dasyurus maculatus* and *Dasyurus viverrinus* respectively). Pelion Plains is also home to the Tasmanian Devil (*Sarcophilus harrissii).* Two monotremes - the Platypus (*Ornithorhynchus anatinus*) and the Echidna (*Tachyglossus aculeatus*) inhabit the area. Pelion Plains is also home to several smaller mammals including the Long-Tailed Mouse (*Psuedomys higginsi)*, the Dusky Antechinus (*Antechinus swainsonni)*, the Swamp Antechinus (*Antechinus minimus)*, the Eastern Pygmy Possum (*Carcartetus nanus*), the Long-Nosed Potoroo (*Pototous tridactylus*) and the Swamp Rat (*Rattus lutreolus)*. Several species of bat also inhabit the Pelion Plains (Hocking 1979:121-125; Watts 1987). Introduced mice and rats are also commonly found around huts in this area. These include the Black Rat (*Ratus rattus*) and the House Mouse (*Mus musculus*) (Watts 1987).

Several of these species might be expected to dig or scratch around buried human faeces. Both of the Quolls and the Tasmanian Devil are the most likely animals consume human wastes, along with the introduced mouse and rat. All of these animals are frequently sited around the huts and toilets of the Pelion Region.

4.4 Description of Sample Sites along Douglas Creek

Running water at Pelion Plains is abundant, with several tributaries flowing into Douglas Creek. The most significant tributary for this investigation, is located just north west of the New Pelion Hut toilet. Effluent leaching from this toilet will be transported via this tributary to Douglas Creek (see Figure 4.2). Surface waters flow over communities of buttongrass moorlands, staining the water a characteristic deep brown colour. This colour arises through the slow decomposition of moorland peats, which make available abundant quantities of fine particulate and dissolved organic matter. Vegetation also influences the high acidity and the low bicarbonate content of waters from these peat and buttongrass communities (Lake *et al.* 1979:103).

4.4.1 Sample Site Selection

Site selection was based on the hypothesis that human wastes produce a detectable impact on water quality at the Pelion Plains region. To examine this hypothesis, the five sites were distributed spatially along Douglas Creek (see Figure 4.2). Table 4.1 describes the characteristics found at each sampling site along Douglas Creek at it flows across Pelion Plains.

Importantly, site DC-1 was selected as a reference site in this investigation as it is located upstream from human activity and infrastructure. It is likely, therefore that results for site DC-1 will reflect background contamination levels for this area.

Table 4.1 Douglas Creek Sample Site Descriptions

	Vegetation	Substratum Description (%)	Width – approx. metres	Approx. depth at medium flow	Flow	Access / Use	Drainage
DC-1	Tall rainforest riparian vegetation overhanging at edges. Significant shading from overganging vegetation	Boulder = 5% Cobble = 30% Pebble = 50% Gravel = 15% Logs at edges	5.4	30 cm	Fast laminar flow	Reference site, upstream of all infrastructure	No significant runnels or drainage lines
DC-2	As above	Boulder = 40% Cobble = 40% Pebble = 10% Gravel = 10%	3.4	1.2 metres	Pools laminar flow	May be used for swimming	Below the drainage point for Cradle Mountain Huts toilet and waste water run-off
DC-3	As above	Cobble = 55% Pebble = 40% Gravel = 5%	5	20-30 cm	Medium flow	Main water collection point. High significance - public health and safety. Most disturbed site and some bank erosion occuring	Diffuse run-off from concentrated visitor activities
DC-4	Overhanging buttongrass & occasional tree. No significant shading	Cobble = 55% Pebble = 40% Gravel = 5%	Small island at low-medium flow, each side 1.5	30 cm	Medium	Track junction for Mt Oakleigh & Arm River. Log brigde. Drinking water collection for these tracks	Downstream from main camping sites surrounding New Pelion Hut
DC-5	As above	Bedrock	3	2 metres	Faster flow mild turbulence	Access difficult, downstream from swimming hole and water collection at bridge	Below drainage point of Old Pelion Hut toilet & drainage from New Pelion Hut toilet

Bedrock
Boulder (>256 mm)
Cobble (64-256 mm)
Pebble (16-64 mm)
Gravel (4-16 mm)
Sand (1-4 mm)
Silt or clay (<1 mm)

Various factors are known to decrease the number of enteric bacteria present in the water. These factors include sedimentation, predation, sunlight, temperature, salinity and nutrient deficiencies (Davies and Evison 1991:265). As differences between these various factors can alter the number of enteric bacteria present any differences between sites may be important.

4.5 CLIMATE

The Pelion Plains area has a very marked summer and winter although snow can fall year round (Pemberton 1986:15). By averaging the data from the two nearest stations, Cradle Valley (Waldheim – altitude 920 metres) and Lake St Clair (750 metres), the climatic data for Pelion Plains were derived. This is possible because Pelion Plains (850 metres) is approximately halfway in both distance and elevation between the two.

Rain, snow, hail, fog, mist and rime contribute to precipitation within the study area (Edwards 1973). Figure 4.3 and Figure 4.4 provide information on the temperature and rainfall for Pelion Plains.

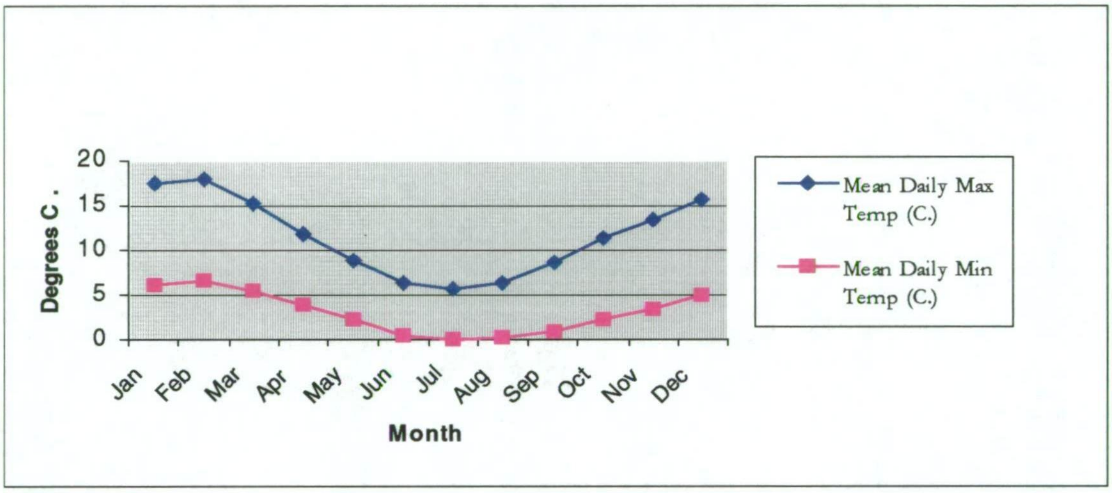

Figure 4.3 Mean Daily Minimum and Maximum Temperature for Pelion Plains
Source: Bureau of Meteorology

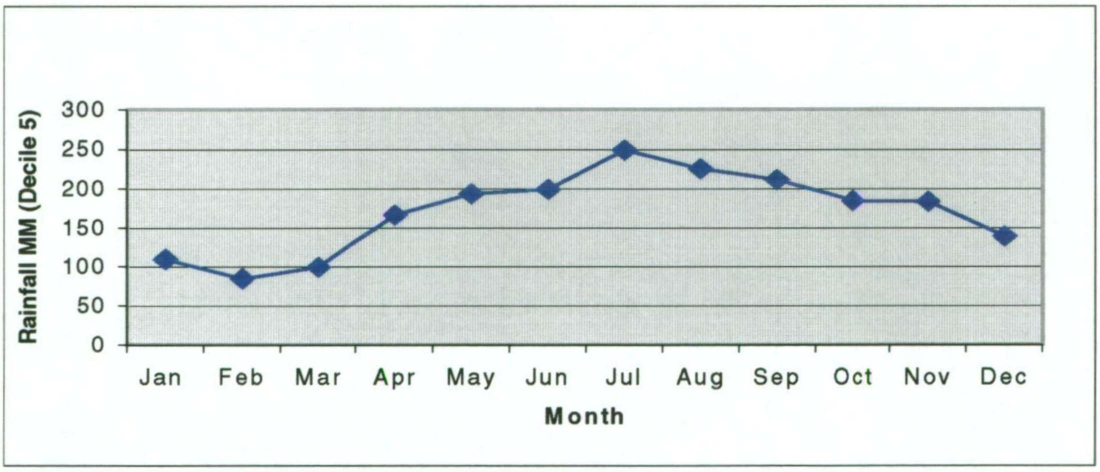

Figure 4.4 Median Rainfall for Pelion Plains
Source: Bureau of Meteorology

4.6 Human History and Land Use

Aboriginal people most likely accessed the Pelion Plains via the Forth and Mersey Valleys (Ryan 1982; Thomas 1987). Europeans first visited the area to survey for transportation routes, and for prospecting and mining. In 1892 a copper-bearing lode was discovered on the Pelion Plains. From 1893 sections of Douglas Creek were intermittently toiled by both individuals and syndicates (Byers 1996:50-52). Old Pelion Hut, an existing small timber hut sleeping eight, was built in 1895 as accommodation for the nearby copper mine.

The next visitors were trappers and people associated with cattle grazing. According to Cubit and Murray (1988) wild cattle roamed the Pelion Plains area from the 1880s to 1948. Many local bushmen acted as guides for intrepid tourists from approximately 1910 onwards.

New Pelion Hut (the most utilised hut today) was built in 1989, and is the third hut on the site. The original, built in 1936, was destroyed by fire in 1950, as was its replacement in 1967. The current hut is galvanised iron and sleeps up to twelve people. Camping in the area is widespread with concentrations along the western bank of Douglas Creek. A Ranger's hut also has been developed at Pelion Plains south of the New Pelion Hut very close to Douglas Creek (see Figure 4.2).

4.7 Management

Joint Commonwealth-State Government arrangements are in place to oversee management for the WHA. These include agreed funding arrangements tied to the implementation of management plans. The Tasmanian Parks and Wildlife Service is the primary management agency.

The policy framework and management prescriptions for the WHA are prepared as management plans under the *National Parks and Wildlife Act 1970*. These plans provide the management framework within which subsequent implementation and further detailed planning will take place. These plans also set objectives for the WHA, define management prescriptions both as policy and as management actions, and establish a monitoring system to evaluate whether these objectives are achieved (PWS 1997:12).

4.7.1 Zoning

One of the primary management tools within the WHA Management Plan is the zoning scheme. This scheme is designed to manage diverse forms of recreation and infrastructure whilst conserving wilderness quality and maintaining values. The zoning was conceived to ensure the maintenance of a wide range of available experiences for visitors whilst minimising conflicting recreational impacts. The Overland Track is managed as a *Recreation Zone*, while both Cradle Mountain and Cynthia Bay form *Visitor Services Zones*. A *Recreation Zone* (as opposed to a *Wilderness* or *Self Reliant Recreation Zone*) is designed to facilitate major walking, boating and vehicle activities, permits high volumes of overnight walking and remote infrastructure (for example huts and toilets) and highly serviced interpretation and signs (PWS 1997:56).

4.8 Visitor Profile

Continual upgrading of the Overland Track and the provision of tourist infrastructure has increased the accessibility of this area. Increased interest in nature based activities, increases in leisure time, availability of comfortable equipment, and active marketing have vastly raised the profile of the Tasmanian wilderness, and led to an increasing number of visitors to the Overland Track (Inter-agency Working Party [Statewide Walking Tracks Strategy] 1997:2).

Results of visitor surveys on the Overland Track, conducted by the Parks and Wildlife Service (1991-92), indicated that 26 per cent of visitors were from Tasmania; 22 per cent from Victoria; 23 per cent from New South Wales; three percent from South Australia; and nine per cent from other states. Overseas visitors constituted 14 per cent of the total: two thirds of whom were from Europe; 10 per cent from Canada; and 13 per cent from New Zealand. Two-thirds of walkers were between 16 and 35, and roughly two thirds were male (Hawes 1994:61-63).

4.9 Commercial Operations

The WHA is central to the Tasmanian tourism industry and provides a key marketing focus. The Overland Track is particularly important as it allows relatively easy access to one of the best known and most scenic parts of the WHA. Various concessions have been granted to allow commercial operations within the WHA.

Approximately 11 private guiding operations run organised tours along the Overland Track (Inter-agency Working Party [Statewide Walking Tracks Strategy] 1997:Appendix B). All operations use public facilities, with the exception of Cradle Mountain Huts which has exclusive access to five private huts, one of which is situated within the study area at Pelion Plains (see Figure 4.2).

4.10 Toilet Systems at Pelion Plains

Three toilet systems are currently in operation at Pelion Plains. A simple pit toilet system is in place near Old Pelion Hut (see Figure 4.2). The Old Pelion pit toilet was closed in mid February 1998 as the contents were spilling over the rocks that support it (see Plate 5.3).

In 1988, Clivus Multrum dry-composting toilets were built into all of the private huts on the Overland Track including the one at Pelion Plains. These toilets, designed in Sweden, have proven incapable of successful composting in the WHA (Crennan 1995).

During the early 1990s Leonie Crennan in conjunction with Department of Environment and Land Management (DELM), began investigating alternatives to the Clivus Multrum system. The system that showed the most promise was the Batch toilet system. A prototype was developed in order to test its potential for the cold, wet remote areas of Tasmania. In November 1992 the first Cage Batch toilet was installed at Pelion Plains (Crennan 1995). The cage Batch system works on the principle of two alternating chambers. One chamber is used while the other is left fallow to compost. By 1998 the toilet had not required emptying, indicating some reduction in waste volume due to a more effective composting process. A detailed discussion of the effectiveness of these systems occurs in Chapter 5 (section 5.7.1, 5.7.2, and 5.7.3).

4.11 Water Supply at Pelion Plains

Tank water is not provided at either the public or the Ranger's huts in the Pelion area creating considerable pressure on particular areas of Douglas Creek, especially in the vicinity of New Pelion Hut and site DC-3.

Cradle Huts have a number of tanks collecting water from the hut roof providing tapped water for three sinks and two showers. Occasionally demand exceeds supply and water is pumped directly from Douglas Creek with the aid of a motor driven pump. All water used by people staying in the Cradle Mountain Huts remains untreated.

4.12 CONCLUSIONS

The Pelion Plains area provides an ideal location for the assessment of microbiological water quality analysis within the Tasmanian WHA. It receives a high number of visitors annually from a variety of backgrounds, has a diversity of toilet infrastructures and a single source of drinking water, Douglas Creek. It also has an anecdotal history of water quality problems. The following chapter will describe in detail the traditional methods used for investigation of microbiological water quality, and present and discuss the findings.

CHAPTER 5

Microbiological Indicator Organisms and Douglas Creek

5.1 INTRODUCTION

A pilot microbiological examination was undertaken on the surface waters of Douglas Creek, within the Pelion Plains region of the Tasmanian WHA (see Figure 4.2). In Tasmanian wilderness areas, surface waters are traditionally consumed without treatment as minimal warning is given regarding possible contamination. This situation continues despite anecdotal evidence of health-related problems in some areas and negligible testing. Recently a move has begun to test surface waters in some heavily used areas within the WHA. From a management perspective, however, information is seriously lacking due to the absence of baseline data from which to make any informed assessment or to assess changes. The aim of this investigation is to see if there are any detectable impacts from faecal contamination and to identify factors which may influence levels of faecal pollution in the surface waters used for drinking at Pelion Plains. Particular emphasis will be given to the traditional indicator method regarding its applicability for use in remote environments.

5.2 METHOD

The selection of analytic criteria and the assessment of results is vital to the success of any water-monitoring program. At present, there are no key water quality criteria or guidelines specifically developed for the protection of aquatic values for wilderness water in Australia. The available assessment method and guidelines relate only to drinking water subjected to treatment. As wilderness water is generally consumed untreated in Tasmania, these guidelines may not be appropriate.

Monitoring water for specific bacterial, viral and protozoan pathogens is complex, expensive and time consuming. Analysis of microbiological quality is, therefore, largely dependent on relatively rapid and simple tests for the presence of indicator organisms (NHMRC and ARMCANZ 1996:2-10). The use of bacteria as indicators of the sanitary quality of water originated in 1880 with the work of von Fritsch (Geldrich 1966:3). Since then, the concept of indicator organisms has been widely adopted as a determinate of faecal pollution in waters. As Faecal coliforms are excreted in large numbers in faeces (a human may discharge as many as 100 to 400 billion per day) they represent the most commonly used indicator of faecal pollution (Schmitz 1996:68). For the purposes of this investigation, a secondary indicator bacterium, Faecal streptococci, was also used. The ratio of Faecal streptococci to Faecal coliforms has traditionally been used to differentiate between human and animal sources of contamination, however, this method has received a number of recent criticisms (see section 6.2). Epidemiological evidence, however, suggests that the presence of Faecal streptococci in waters presents a risk to users (Sinton, Donnison and Hastie 1993:125).

5.2.1 SAMPLING

Microbiological sampling of Douglas Creek occurred on five separate occasions (see Table 5.1). Rainfall information for each day of sampling is provided in Appendix 1.

Table 5.1 Microbiological Sampling Events

Sample Event	Sample Date	Sites Sampled
1	29.1.98	DC-1-2-3-4-5
2	2.2.98	DC-1-2-3-4-5
3	8.2.98	DC-1-2
	9.2.98	DC-3-4-5
4	17.2.98	DC-1-2-3-4-5
5	19.3.98	DC-1-2-3-4

During the third visit, constituting a storm event, two of the five samples were collected during the height of a storm and peak flow period (see Table 5.1). Due to failing light the other three sites were sampled early the next morning on 9 February 1998. This temporal distribution may be useful in providing an indication of faecal flux during and directly after a storm event. While the fifth sampling event occurred outside of the recommended four-week period for the assessment of drinking water quality (ANZECC 1992), it was undertaken at this time because a helicopter was available. The use of a helicopter, whilst compromising the recommended sampling regime, permitted the concurrent use of equipment and testing that otherwise would not have been possible. Details of these tests are discussed in Chapter 6. As time was restricted on this occasion, only four samples were collected but, as discussed in Chapter 6, other more detailed tests were performed.

5.2.2 Sample Collection Procedure

Due to the remoteness of Douglas Creek a number of logistical difficulties had to be overcome to ensure compliance with sampling guidelines (as stated in section 5.5). Access to Douglas Creek at Pelion Plains is most easily gained via a six to eight hour return walk along the Arm River Track (see Figure 4.2). The drive from Hobart to the beginning of the Arm River Track is approximately five hours. It took approximately two hours to collect the five samples from the various sites. Therefore, a return journey from Hobart to Pelion Plains, including time to collect samples, requires approximately 18-20 hours. Samples had to be delivered to the Aquahealth Laboratory in Hobart within 24 hours of collection, and needed to arrive before 1400 hours so processing could begin that day. Because of these time requirements, samples were collected at approximately mid-day. This time schedule facilitated walking in and out in a single day, and therefore allowed the reduction of the amount of camping equipment carried. This was desirable because of the combined weight of the water samples and chilling agent was already considerable.

It was also intended to include a storm event in the sampling to investigate its impact on bacterial loading. A storm event occurred across Tasmania on 8 February 1998. The author drove to Arm River and walked in on the late afternoon of 8 February, and stayed the night at Pelion Plains. This sampling event, due to the storm, was an exception to the normal sampling regime because of the night spent at Pelion Plains.

After sample collection, changes in the chemical and biological characteristics may occur during storage, resulting in loss of representativeness of prevailing microbiological conditions at the site sampled. In order to reduce the likelihood of changes occurring, it is recommended that samples be chilled to less than 10°C and concealed from light. While some authors suggest that samples be analysed within six hours of collection (Bitton and Greeson 1989) others conclude that minimal alteration occurs during the first 24 hours of storage (Cohen and Shuval 1973; Bartram and Ballance 1996; Garland pers. comm. 1998). Because of logistical difficulties encountered in sampling in a remote environment, samples were stored overnight but analysis occurred within a 24-hour period.

5.2.3 Microbiological Sample Collection

The sampling process was coordinated with the Aquahealth Laboratory, Hobart.

The process for the collection for water samples was as follows:

1. plastic sample containers (500 mL, Nalgene) were used to collect water samples for analysis. These sample bottles were provided, cleaned and prepared by the Aquahealth Laboratory prior to each sampling event;
2. waterproof labels were attached to each bottle prior to sampling. These labels listed the location, site code, date, time of collection, person collecting and test to be undertaken;
3. the cap was removed at the sampling site and held with the bottom of the cap facing the ground and care was taken not to place anything inside the lid to prevent contamination;
4. the bottle was held at the base and plunged neck downwards into the water to a depth of approximately 30 cm below the surface;
5. the bottle was then turned so the mouth was directed towards the current to allow quick filling (the bottle was not rinsed);
6. when the bottle was full it was removed from the water and the lid was immediately replaced;
7. water samples were immediately placed in a box with freezer packs to keep them chilled (<10°C) and concealed from light;
8. the samples were then carried in a pack for 3-4 hours to a car where they were placed in a chilled esky for transportation to the Aquahealth Laboratory.

5.2.4 Detection of Faecal Bacteria

Two techniques are commonly used to detect the presence of bacteria in water; the multiple fermentation tube technique, and the membrane filtration method (Bartram and Pedley 1996:239). The membrane filtration method was used in this investigation and performed by the Aquahealth Laboratory staff.

The membrane filtration method provides a direct count of indicators present in a given sample of water. A measured volume of water (100mL) is filtered (under vacuum) through a cellulose acetate membrane of uniform pore diameter (0.45μm). Bacteria are retained on the surface of the membrane, which is then placed on a selective medium in a sterile container and incubated. If bacteria are present in the water sample, characteristic colonies form that are then directly counted. This technique operates on the assumption that each bacterium, clump of bacteria, or particle with bacteria attached, will give rise to a single visible colony. Each of these clumps or particles is, therefore, a colony forming unit (cfu) (Bartram and Pedley 1996:249). Results for Faecal coliforms and Faecal streptococci for this report are presented as the number of cfu per 100 mL of water.

5.3 LIMITATIONS

Due to financial and logistical constraints of water quality assessment in a remote area a number of limitations of method were encountered. Sampling for faecal contamination is very costly and the amount of finance available was limited. Information provided in this chapter, therefore, represents a series of snapshots rather than a complete and comprehensive analysis of faecal contamination. Due to this lack of replication and problems encountered in gaining accurate rainfall information (see section 5.3.2), it was decided not to conduct detailed statistical analysis on microbiological results.

Other limiting factors were time constraints and the weight of equipment that had to be carried to the sampling area. The combined weight of the collected water, the chilling agent and other equipment required when walking in a remote environment was considerable. This weight therefore limited the amount of other equipment that could be carried. Due to these limitations and time restrictions (see section 5.2.2), a number of traditional methods used in water quality analysis were overlooked to ensure adequate precautions were taken to keep water samples chilled and delivered to the laboratory within a strict time frame.

5.3.1 FLOW RATE MEASUREMENTS

A number of authors highlight the importance of hydrological measurements in studies of this kind, as conclusions based wholly on pollutant concentrations can be deceptive (Kuusisto 1996:303; Chapman, Jackson and Krebs 1996:245). Variations in hydrological conditions have important effects on water quality. In rivers, such factors as the discharge (the volume of water passing through a cross-section of the river in a unit of time), velocity of flow, turbulence and depth all influence water quality (Kuusisto 1996:303).

A large number of techniques exist to determine flow rates. The most accurate method is to use a current meter which was, however, due to weight and time restrictions, not suitable for this investigation. Measuring the time required for a weighted float to travel a fixed distance along the stream can, however, be used to make a rough estimate of velocity. Douglas Creek is nevertheless not suitable for this technique as it has few of the ideal characteristics for this method. Furthermore, as available time was a limiting factor, and as this method requires two people to accurately take these measurements, it was decided that that any reading of velocity would be too inaccurate to be of any real value. While it can be misleading to report pollutant concentration without associated flow rate data (Cullen 1995) it was not possible in this investigation.

5.3.2 RAINFALL DATA

The determination of the average depth or volume of precipitation over an area is commonly applied to this type of microbiological analysis. It is, however, not possible to measure directly the volume of precipitation falling on a natural basin such as Douglas Creek as it is in a remote wilderness area. Consequently rainfall information from the closest two sites were correlated (see Figure 1 and 2, Appendix 1). Figure 2 (Appendix 1) indicates that there is a reasonable correlation between the two rainfall stations on a day by day basis with $R^2 = 0.85$. While Cradle Valley has a slightly higher rainfall and it is considered highly likely due to altitude and topographic position that Pelion Plains receives similar rainfall.

Due to potential inaccuracies in rainfall data no detailed statistical analysis of the relationship between rainfall and indicator levels was undertaken because it may be too inaccurate to be of any real value. It is recognised that this represents a severely limiting factor in the analysis of the faecal contamination of Douglas Creek, but that it also characterises one of the difficulties encountered when working in a remote area.

5.4 MICROBIOLOGICAL INDICATOR ORGANISMS: THE RESULTS

5.4.1 FAECAL COLIFORMS

Faecal coliforms are a subset of the coliform group, and are found in the intestinal tract of humans and other warm-blooded animals. They include all coliforms that can ferment lactose at 44 to 44.5°C (Bitton 1994:102; NHMRC and ARMCANZ 1996:2-13). Faecal coliforms are a specific indicator of faecal contamination as they are the most likely to have originated in the gut (as opposed to total coliforms) (NHMRC and ARMCANZ 1996:2-13). As their presence is indicative of faecal contamination they were selected for use in this investigation. Table 5.2 displays details of the microbiological indicator results for Faecal coliforms.

Table 5.2 Faecal coliform Results (cfu) per 100/mL for Douglas Creek

Sample Site	Date Collected	FC/100mL
DC-1	29.1.98	80 (est)
DC-2		91
DC-3		280
DC-4		260
DC-5		370
DC-1	2.2.98	24
DC-2		42
DC-3		32
DC-4		47
DC-5		59
DC-1	8.2.98	280
DC-2		370
DC-3	9.2.98	70
DC-4		180
DC-5		410
DC-1	17.2.98	4 (est)
DC-2		10 (est)
DC-3		13 (est)
DC-4		25
DC-5		25
DC-1	19.3.98	1 (est)
DC-2		6 (est)
DC-3		20
DC-4		6 (est)
DC-5		

est = estimate

Figure 5.1 indicates that there may be a relationship between temporal distribution of sampling and faecal contamination levels.

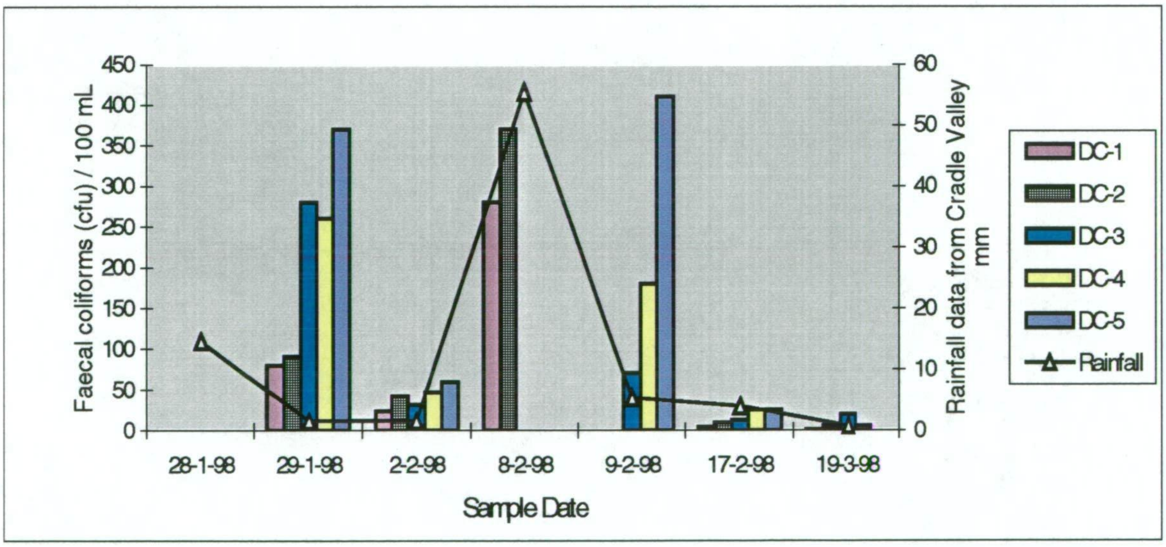

Figure 5.1 Faecal coliform Levels and Rainfall Data for Douglas Creek

The two sample events of 29 January 1998 and 8-9 February 1998 demonstrate an increase in contamination levels found in Douglas Creek in comparison with the other sample events. Site DC-3 on 9 February 1998, however, does not have increased contamination levels for this sample event.

Due to the potential importance of rainfall on faecal contamination levels (see both section 5.3.2 and 5.6.2), rainfall levels for Cradle Valley has been incorporated into Figure 5.1. While there may be some variability between the actual rain that fell at Pelion Plains and the data presented (as discussed in section 5.3.2), it is possible that this data provides an indication of the relationship between rainfall and Faecal coliform levels (full details of rainfall data are presented in Appendix 1). The rainfall for 28 January 1998 is included in Figure 5.1 as the flush-through time for Douglas Creek is unknown and it may have influenced the contamination levels for the sample event of 29 January 1998. This rainfall is likely to have been part of a three day period of light rain which was preceded by three relatively dry days. The second sample event was the third day of an eight day dry spell. The third sample event corresponds with a day of high rainfall. The fourth sample event was similar to the first with the exception of high rainfall approximately one week previously. It is likely that the fifth sample event occurred at the end of a five day period of light rain, but is difficult to assess due to the differences in rainfall between Cradle Valley and Lake St Clair for the two preceding days.

Data in Figure 5.1 suggests that Faecal coliform levels are spatially variable. Site DC-1 demonstrates lower results on each sample event (with the exception of the 8-9 February 1998, which is expected due to anomalous sampling times). As previously discussed (section 4.4.1) DC-1 was selected as the reference site for this investigation as it is situated upstream from any huts or camping areas. It is therefore highly unlikely that it would receive any human faecal input, and would thus contain faecal contamination from animal sources only. Faecal coliform results for Site DC-1 are likely to represent the background levels for Douglas Creek on which human faecal input is assessed.

The remaining sites were selected and spatially distributed along Douglas Creek in an attempt to detect faecal input from the various toilet infrastructures (see Table 4.1). As the levels of Faecal coliforms generally increase as Douglas Creek flows through the study area, it is possible that human activity and infrastructure is influencing contamination levels.

As there is a rise in Faecal coliform levels between DC-1 and DC-2 on every sample event (see Figure 5.1) it is possible that some form of human faecal input is occurring between the two sites. As noted in Table 4.1, site DC-2 was located where it is unlikely to be affected by human related activities other than Cradle Mountain Huts, as it is upstream from other camping areas or huts. The difference in levels of Faecal coliforms is therefore possibly related to effluent leaching from the Cradle Mountain Huts Clivus Multrum toilet, as it represents the only consequential variant between the two sites. It is, for example, considered unlikely that there would be any change in the concentration of animal faecal input between the two sites as there are no major differences in vegetation types.

Similarly site DC-3 displays higher Faecal coliform levels than the reference site DC-1 (on all sample events) (see Figure 5.1). An exception occurred on 9 February 1998 when DC-3 was sampled following a storm. This inconsistency was therefore anticipated due to the time of sampling, which occurred more than ten hours later than the sampling for the two preceding sites (DC-1 and DC-2). Site DC-3 was sampled more than 12 hours after the rain had ceased and the lower result may therefore reflect the influence of catchment flushing times.

The increased levels of coliforms detected at DC-3 are particularly concerning as it is representative of the water most likely to be consumed by visitors to Pelion Plains. As there is no additional toilet infrastructure located between sites DC-2 and DC-3, toilet infrastructure is not likely to be a contributing factor in the increased contamination levels recorded at this site. It is argued therefore, that the increased levels of coliforms at site DC-3 compared with site DC-2 are due to visitors using alternative disposal methods for their wastes, or to the influence of other activities such as water collection and washing. These activities are likely to disturb sediments which can increase the levels of microbiological indicator organisms (this is discussed further in section 5.8).

Site DC-4 consistently demonstrated higher levels of Faecal coliform contamination than the reference site (again with the exception of the sample event of the 8-9 February 1998, which is discussed above). Site DC-4 is a water collection point for people walking either the Mt Oakleigh or Arm River tracks. DC-4 was located to allow the detection of faecal contamination arising from the large number of campsites to the west of the main camping area around the New Pelion Hut Site. As this site exhibits high levels of Faecal coliforms (especially in comparison to DC-1) it is possible that some form of human faecal contamination is being detected.

Site DC-5 on every sample event displayed consistently higher levels of contamination than all other sites. Site DC-5 is situated within 50 metres of the pit toilet at Old Pelion

Hut and would also collect input from the New Pelion Hut toilet (via a tributary, see Figure 4.1). As there is no major ecological distinction between DC-5 and DC-4, except for a increased visitor presence, a hut, and a toilet, it is considered likely that the increase in Faecal coliform levels is human in origin. Faecal coliform results, particularity at sites DC-5 and DC-3 suggest that moderate contamination is occurring along Douglas Creek, and it is considered likely that some of this is human in origin.

5.4.2 FAECAL STREPTOCOCCI

Since Faecal streptococci commonly inhabit the intestinal tract of humans and warm-blooded animals, they may be used to detect faecal contamination in water. While they are a less sensitive indicator than Faecal coliforms, members of this group persist well and do not reproduce in the environment (NHMRC and ARMCANZ 1996:2-14). Faecal streptococci data are shown Appendix 2 and in Figure 5.2.

The Faecal streptococci levels display a high degree of spatial and temporal variability. The highest levels of Faecal streptococci were detected on the first sampling event which occurred on 29 January 1998. The levels of streptococci vary with the levels of Faecal coliforms found in Douglas Creek.

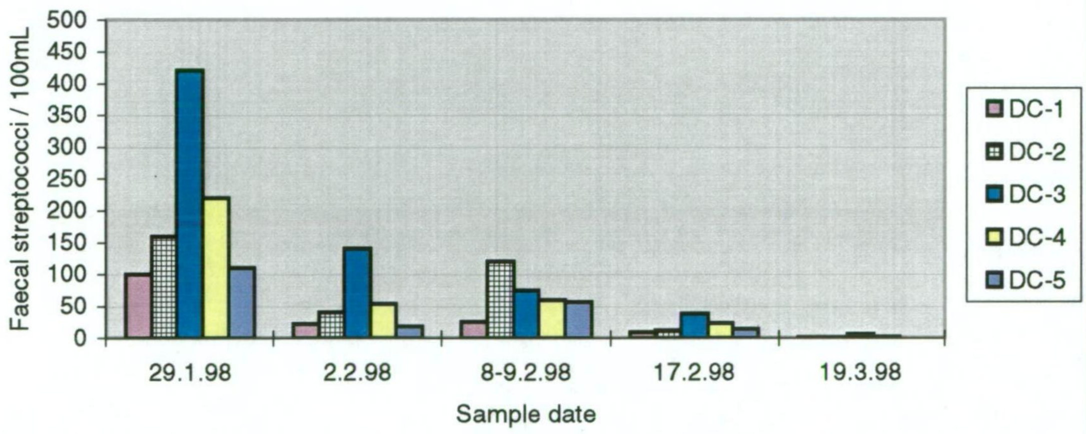

Figure 5.2 Faecal streptococci Levels for Douglas Creek

While Faecal streptococci contamination occurs throughout Douglas Creek, levels are generally higher at DC-3 (with the exception of the third sample event [8-9 February 1998] where they are higher at DC-2, and which were possibly influenced by sampling times, as discussed in section 5.2.1). These higher readings are of particular concern as

DC-3 is the main point of drinking water collection for visitors to Pelion Plains. There also appears to be a high degree of uniformity in site concentrations regardless of the intensity of contamination between each sample event (see Figure 5.2).

DC-1, the reference site, consistently contains the lowest level of Faecal streptococci (with the exception of 2 February 1998), with DC-2 containing slightly higher levels. There is then a peak at DC-3 before contamination levels decrease at DC-4 and another reduction in streptococci contamination levels occurs at DC-5. The results indicate that increased Faecal streptococci levels are found at the same areas as increased human impacts.

5.5 STANDARDS FOR WATER QUALITY IN AUSTRALIA

NHMRC and ARMCANZ (1996) and ANZECC (1992) publish standards for drinking water quality and recreational use in Australia, respectively.

For drinking water:

- Faecal coliforms: *no sample should contain any Faecal coliforms in 100 mL* (NHMRC and ARMCANZ 1996).

For primary contact (water used for activities like swimming, bathing and other direct water-contact sports):

- The median bacterial content in samples of fresh or marine waters taken over the bathing season should not exceed:
- *150 Faecal coliform organisms/100 mL (minimum of five samples taken at regular intervals not exceeding one month, with four out of five samples containing less that 600 organisms/100 mL);*

On all occasions the surface waters of Douglas Creek failed to meet the guidelines for drinking water quality in Australia. However, as these standards relate to water subjected to treatment and the water in Douglas Creek receives no treatment (except occasionally on an individual basis) these results were not unexpected due to the presence of animals and human activity within the catchment. While these standards exist to ensure that drinking water is free of disease causing microorganisms (NHMRC and ARMCANZ 1996:2-1), their usefulness within wilderness areas is perhaps limited as the broad scale treatment of water in these areas is inappropriate, and because they provide no indication of the risk associated with consuming contaminated water. It is possible, for example, that no water in wilderness areas is free from indicator organisms due to the presence of wildlife.

With relation to primary contact, the water of Douglas Creek meets the guidelines at all sites except DC-5. Median Faecal coliform values are given in Table 5.3.

Table 5.3 Median Faecal coliform Values for Five Samples

Site	DC-1	DC-2	DC-3	DC-4	DC-5	Total Median
Median Faecal coliforms /100 mL	24	42	32	47	214.5	42

5.6 Discussion of Microbiological Quality at Douglas Creek

The presence of Faecal coliforms in the surface waters of Douglas Creek indicates that faecal contamination is occurring and also indicates that a significant health risk may be associated with consumption of or primary contact with this water. Even in low flow periods, the levels of coliforms pose a health risk to visitors who consume the water untreated. During periods of rain the risk may be seriously magnified.

The presence of Faecal streptococci in the surface waters of Douglas Creek is even more alarming because they are more persistent in water than Faecal coliforms and they also mirror the presence of certain persistent pathogens which die off slowly (for example, viruses) (Bitton 1994:2). It is also possible to isolate Faecal streptococci from water that contains few or no Faecal coliforms as, for example, when the source of contamination is distant either in time or space (Bitton 1994:2). Therefore, the presence of Faecal streptococci in Douglas Creek is particularly disturbing. Factors potentially affecting levels of faecal contamination at Douglas Creek and the risk to visitors are discussed below.

5.6.1 Faecal coliform and streptococci Survival Rates

At a temperature of approximately 6°C faecal bacteria have been known to survive for more than 45 days, and even longer survival periods are possible for Faecal streptococci (Zieminska *et al.* 1980; Cohen and Shuval 1973:85). As water in Douglas Creek is approximately 7°C at all sites, faecal bacteria may be able to survive for long periods.

Survival rates are also related to two principal variables; nutrient concentrations and radiation-induced damage (Kay and Hanbury 1993:143). As indicated in Table 4.1, significant differences in shading occur between sites DC-1-3 and sites DC-4-5.

As the water in Douglas Creek is stained a characteristic brown from tannins leached from the surrounding vegetation, the impact of ultraviolet radiation would be lessened due to these sunlight absorbing substances (Davies and Evison 1991:265; Sinton, Donnison and Hastie 1993:124). The impact of sunlight is also much less for fresh water than marine water. This is due to the more favourable conditions which prevail in freshwater for enteric bacteria and associated pathogens. Differences in UV-radiation does not appear to be a contributing factor to levels of detected cfu's in Douglas Creek as sites receiving less sunlight (DC-1-3) generally had lower levels of contamination than sites receiving higher amounts of sunlight (DC-4 and 5). Further research is required to assess the survival rates of bacteria in the tannic waters of the Tasmanian WHA.

The balance between addition and loss (through mortality, dilution and flushing) will also determine survival concentrations (Kay and Hanbury 1993:143). It is important, therefore, to consider variables such as rainfall in determining the influences on contamination levels.

5.6.2 Contamination and its Relationship to Rainfall

Coliform contamination of wilderness water is related to the duration and amount of precipitation. While it was not possible to measure directly the amount of rainfall at Pelion Plains (as discussed in section 5.3.2), several studies indicate that water quality decreases with precipitation and significant variations in pollutant concentrations are common during a storm or heavy rain event due to fluctuations in load rates (Silverman and Erman 1979; Evison 1988; Niemi and Niemi 1990:331; Stukel *et al.* 1990).

Increases in levels of contamination during a storm event may also relate to the wash-out of bacteria existing in stream bed sediments as stream discharge increases (Hunter and McDonald 1991:447). While stores of bacteria will depend upon the balance between faecal input rate, bacterial die-off and the rate of removal of bacteria, sudden increases will occur if sediments are disturbed (as during a storm). Unfortunately, minimal investigation has been undertaken on the roles of sediments and their effect on water quality in wilderness environments, despite having figured importantly in the overall water quality of a wide range of aquatic environments (Tunnicliff and Brickler 1984:909). Human activity (such as swimming) may also disrupt sediments leading to increases in bacterial counts (the impact of swimming at Douglas Creek is discussed in section 5.8)

Studies on storm events and their impact on water quality consistently report a peak in concentration of pollutants during the beginning of a storm and a decrease in concentration as the storm progresses (OECD 1986). Although variations in pollutant concentration are obviously related to surface run-off and hence the nature of rainfall events, further research is required to examine the relationships between pollutant concentrations and antecedent rainfall.

Most rain falling on a catchment does not immediately run off the land surface, but soaks into the soil to provide a reservoir which supports the dry weather base-flow of the upland streams. To this volume of water a flood-flow may be added, dependent on the amount of rain that has fallen and the ability of the catchment soils to soak it up and store it. The flood-flow may carry much more organic debris such as surface leaf litter and soil particles eroded from the land (Moss 1988:60). It is therefore likely that the longer the period between rain events, the more material there is to be washed off and the greater the shock loading into the receiving waters (where large amounts of waste are added in a short time period). Increased intensity in Faecal coliforms in Douglas Creek appear to relate to increased rain events (although, as discussed in section 5.3.2, statistical analysis of this relationship was deemed inappropriate).

5.7 A Discussion of the Relationship Between Microbiological Quality and the Toilet Systems of Pelion Plains

As discussed in Chapter 3 (section 3.4.2) evidence suggests that human use and visitation will result in increases in enteric bacteria in surface waters in wilderness areas. The results of this study further suggest that one of the main influences on the spatial distribution of faecal contamination is the location of human activity and toilet infrastructure.

The toilet systems used extensively throughout the Tasmanian WHA have unfortunately been adopted without adequate planning or consideration of the type and quantity of usage, nor of limitations determined by site (Crennan 1992). The failure of these systems to operate effectively is largely related to climatic factors, which result in slow anaerobic decomposition (as discussed in Chapter 2 section 2.2.1.2) and shock loading. Low levels of maintenance also impede the success of the decomposition process in these toilet systems.

5.7.1 Clivus Multrum Toilet - Cradle Mountain Huts

Cradle Mountain Huts has a Clivus Multrum system in use at Pelion Plains. Unfortunately the Clivus Multrum toilet system has proved incapable of successful operation in this environment. While the toilets are partially emptied of semi - composted wastes in late January or early February, most wastes remain for several months, the toilets being only fully emptied prior to each guiding season (approximately mid October) (see Plate 5.1)

As this system fails to successfully compost wastes, and is not capable of removing liquid run-off, there is considerable scope for pathogen transmission into the surrounding environment. Byers (1996) found that effluent collected from the Cradle Huts toilet at Pelion Plains contained extremely high numbers of Faecal coliforms - between 9×10^8 per 100 mL- and *E. coli* levels of $<1 \times 10^8$ per 100 mL. This toilet therefore clearly represents a significant source of faecal contamination to the surrounding environment.

Due to the position of this toilet system and the surrounding topography, the liquid run-off leaching from it can be transported to Douglas Creek (see Figure 4.2).

Plate 5.1 Helicopter Removing Human Wastes from the Cradle Mountain Huts Toilet

While further research is required to accurately estimate the amount of rainfall required to transport pathogenic material into Douglas Creek, and its exact route, this survey detected faecal contamination in the Creek at the approximate location that effluent from this toilet would enter Douglas Creek.

5.7.2 CAGE BATCH TOILET - NEW PELION HUT

The Cage Batch system, which was installed at Pelion Plains in 1992, is managed by the Cradle Mountain National Park (Crennan 1995). This toilet was installed as an attempt to overcome some of the problems experienced with Clivus Multrum systems. While the Cage Batch system proved cheap to install, it has developed some problems relating to its inability to deal with liquid run-off and malodour (Crennan 1995) (see Plate 5.2).

Plate 5.2 New Pelion Hut Cage Batch Toilet Effluent

Byers (1996) sampled effluent which is permanently present at the base of this toilet and found both Faecal coliform and *E. coli* rates per 100 mL to be 2.6×10^4 (see Plate 5.2). Due to surrounding topography and the position of this toilet, effluent leaching from it will be transported when it rains to Douglas Creek via a tributary, which begins just below this toilet and enters Douglas Creek above site DC-5 (see Figure 4.2).

This toilet has also proved incapable of eliminating odour, which may contribute to people using the burial method in the surrounding area. There are several tracks leading to possible sites for personal burial holes behind the New Pelion Hut toilet which indicate that this may be the case. Many bushwalkers have informally indicated that they found the odour of the New Pelion toilet distressing and therefore opted to go elsewhere to use the burial method.

As detailed in Chapter 2, the burial method may not provide adequate protection from contamination, especially given the large number of visitors to Pelion Plains. It also provides easy access for native animals to human faecal wastes. The elimination of odour from the New Pelion Cage Batch toilet would help to alleviate possible problems of the burial method and make the toilet a more attractive option for visitors. This issue is discussed below in section 5.7.3, as this problem is more serious at Old Pelion Hut where the toilet is actually closed.

5.7.3 PIT TOILET - OLD PELION HUT

The Old Pelion Hut pit toilet is situated approximately 50 metres from Douglas Creek (see Figure 4.2). As discussed in Chapter 2 section 2.3.2, pit toilets do not effectively contain harmful pathogens. It is probable that this pit toilet is a source of bacteria, both because of its inability to compost wastes and as the shallow porous soils and underlying bedrock will not appreciably impede seepage. Any drainage leaching from this pit system has only approximately 50 metres to flow down a slope to reach Douglas Creek.

Serious problems occurred with this toilet during the 1997/98 summer when the waste pile became so large it overflowed, and untreated wastes were seen seeping out over the rocks on which the structure was built (see Plate 5.3). The toilet was closed early in 1998 and visitors requested to use either the New Pelion Hut toilet or to bury wastes in a hole 150 mm deep and 50 metres away from water (see Plate 5.4). As the pit toilet was closed at the time of investigation, and as it is an approximately 50 minute return trip to the nearest toilet (New Pelion Hut), it is likely that visitors staying at Old Pelion Hut are using the burial method for the disposal of human wastes.

This information indicates that visitors to Old Pelion Hut are likely to be burying human wastes closer than the recommended distance from a water source. The Tasmanian Parks and Wildlife Service recommend in all other publications a distance of at least 100 metres from water for the burial of human wastes. This situation may therefore be leading to increases in faecal contamination of the surrounding water, as pathogens buried in this method remain viable for long periods of time (as discussed in Chapter 2 section 2.3.1.2).

Plate 5.3 Old Pelion Hut Pit Toilet

As the Faecal coliform results for site DC-5 were higher than those for all other sites at each sample event, and as there are no major differences between site DC-5 and DC-4 (its closest analogue - see Table 4.1), it is possible that effluent from this toilet and the Cage Batch toilet are leaching into Douglas Creek. It is also possible that buried human wastes, which may be consumed by native animals and/or washed into Douglas Creek when it rains, are influencing these coliform levels.

Plate 5.4 Old Pelion Hut Toilet Closed Sign

5.8 Swimming in Douglas Creek and Other Activities Affecting Water Quality

No consistent policy exists regarding swimming or bathing in Douglas Creek. A popular water-hole which is upstream from the main drinking water collection point is often frequented by visitors to the Pelion area. Increasing levels of contamination are known to occur during storm events possibly due to the disruption of sediments containing bacteria. Activities such as swimming or bathing may also upset the stream bed sediment leading to a downstream increase in bacterial loads. A study by Varness, Pacha and Lapen (1978) in a backcountry location examined a possible relationship between rapid increases in bacterial indicators in surface waters and bacterial indicators surviving in sediment. The authors conclude that human recreation activities, such as swimming, caused a stirring of sediments leading to a rapid increase in the number of indicator bacteria found in water samples. Activities such as washing or even collecting water may also stir up sediments and thus lead to a decrease in water quality.

There is also a swimming hole directly above the drinking water collection point for visitors staying at Old Pelion Hut. More research is required to assess the occurrence of swimming in Douglas Creek and its subsequent impact of water quality.

5.9 FACTORS INFLUENCING RISK OF ILLNESS

Numerous factors have to be taken into consideration when attempting to assess the health risk associated with drinking untreated water. The significance of a particular organism in water varies considerably with the disease and local conditions - a potentially pathogenic organism will not always cause symptomatic disease in a particular individual (NHMRC and ARMCANZ 1996:2-6).

The chances of an infection occurring depend on:

- the concentration of pathogenic organisms in the water;
- the virulence of the strain;
- the intake of contaminated water;
- the infectious dose of the particular pathogen;
- individual susceptibility; and
- the incidence of the infection amongst visitors or animals (which will determine the numbers of pathogens being excreted) (NHMRC and ARMCANZ 1996:2-6).

There is no definitive information available which relates the numbers of faecal indicators to absolute degree of infection risk. It is, consequently, impossible to establish the exact risk associated with consuming contaminated water at Douglas Creek.

5.9.1 ACQUIRED IMMUNITY

As pathogenic microorganisms are most likely to access the host via the gastrointestinal tract, a number of factors may play an important role in host resistance to infectious agents. For example, the host may have either natural or acquired immunity to an infectious agent. Other non-specific factors affecting host susceptibility include physiological barriers at the portal of entry such as unfavourable pH, or the presence of bile salts (Bitton 1994).

Acquired immunity develops as a result of exposure of the host to the infectious agent (Bitton 1994:80-81). Such a situation can be seen in some developing countries where the prevalence of pathogens is high and the standard of tap water less than optimal. Visitors who drink the water frequently become ill, while members of the local community, especially adults, appear to suffer minimal morbidity (NHMRC and ARMCANZ 1996:2-7). Evidence for acquired immunity to diseases such as *Giardia* is growing (Craun 1979:129-130; Craun 1990:281).

The fact that individuals may develop acquired immunity to water-borne pathogens is pertinent within the wilderness situation where decision makers (for example, rangers) spend a lot of time in an area. If they do not then suffer any adverse affects from drinking surface water in the wilderness area under their jurisdiction, they may be unlikely to issue any warning to visitors, or initiate any testing. The absence of absolute indicators of risk, and the possibility of rangers acquiring a degree of immunity, brings the relevance of the traditional indicator method into question in wilderness areas. This issue is discussed further in Chapter 6.

5.10 Conclusions

Whilst acknowledging a number of limitations (due to time, weight and the cost of sampling) and the lack of any statistically verifiable relationship between rainfall and contamination levels, it is clear from the sampling undertaken that faecal contamination is occurring at Douglas Creek. It is also clear that, in some cases, people may be consuming water which is unsafe even for recreational contact. This represents a serious problem for managers.

Assumptions that water in wilderness areas is pristine or pure may have serious health implications (Fair and Morrison 1967:802). More detailed investigations, however, are required to gain a more comprehensive picture of contamination levels in Douglas Creek, and of the possible influences on these levels.

Throughout this investigation a number of problems with the traditional indicator method became apparent. These relate to the inability of this method to determine the degree of risk associated with the consumption of contaminated water. This method is also limited in its usefulness in remote environments as replication is required to gain meaningful data and large volumes of water and chilling agents are required. Samples also have to be analysed within 24 hours thus limiting the usefulness of this method in remote environments. However, one of the most significant limitations of this method is its inability to determine the actual source of faecal contamination.

CHAPTER 6

Alternative Methods for Investigating Water Quality: Faecal Sterols and Macroinvertebrates

6.1 INTRODUCTION

The use of the traditional indicator method for detecting faecal contamination in surface waters in wilderness areas is limited for a variety of reasons. In particular, this limitation relates to the failure of the traditional indicator method to reveal a complete picture of faecal contamination. This has serious implications for its use in wilderness environments. This chapter firstly details reasons why the traditional indicator method is limited. It then explores two alternative methods for the detection of faecal contamination: faecal sterols and macroinvertebrates.

6.2 TRADITIONAL INDICATOR METHOD

As discussed in Chapter 5, the traditional method for the detection of faecal pollution in surface water commonly includes tests for coliform bacteria, Faecal coliform bacteria (thermotolerant coliforms), Faecal streptococci (enterococcoi) or *Clostridium perfringens* (Vasconcelos and Anthony 1985:366).

In several cases, however, Giardia cysts have been found in waters that proved negative for coliform testing (Craun 1979:133). Several other studies support this result, and conclude that evidence of bacterial contamination is not an accurate indicator of water quality (Yapp and Wade 1989:10; Kay and Hanbury 1993:217; Bitton 1994:102; Kettlewell 1995:50). This implies that the absence of coliforms does not assure that drinking water is safe and that indicators such as Faecal coliforms have limited value in indicating the potential presence of pathogens such as *Giardia* and *Cryptosporidium* (Craun 1979:127-145; Craun 1990:276; Bitton 1994:95; Steiner, Thielman and Guerrant 1997:333). Furthermore, viruses are also poorly correlated with Faecal coliform levels (Ashbolt 1995). Due to the potential threat posed by *Giardia* and similar diseases in wilderness areas (as discussed in section 3.6.1.1), the usefulness of traditional indicators in wilderness areas is therefore restricted.

Furthermore, the usefulness of traditional indicators is limited because there is no definitive information available to relate numbers of faecal indicators to absolute degrees of infection risk (as discussed in section 5.9). The actual number of pathogens present in surface water at any one time is very rarely determined, and there is no clear evidence as to what constitutes a minimum effective dose. The survival rates of pathogens and Faecal coliforms in surface waters may also be different. This means that pathogens may still be present after Faecal coliforms have died off (Jones and White 1984:219).

As the traditional method uses Faecal coliform bacteria, which are not unique to human intestines but are found in other warm-blooded animals, another major limitation of this method is the fact that the source of faecal pollution is not differentiated. The ability to provide evidence of faecal contamination as well as to differentiate the source would be of immense value to managers of wilderness areas. For all of the reasons discussed above, the use of an innovative method for the detection and differentiation of faecal contamination was trialled on the surface wastes of Douglas Creek.

6.3 FAECAL STEROLS

The traditional indicator method is not specific enough to distinguish divergent sources of faecal matter. Despite this, source identification is often essential to problem resolution and is often inferred from the spatial distribution of contamination levels in relation to identified input from faecal matter. While the ratio between Faecal coliforms and Faecal streptococci has previously been used to distinguish human and non-human warm-blooded animal faecal matter, this method is no longer recommended (Geldreich 1966; Geldreich and Kenner 1969; Lin, Evans and Beuscher 1974; Pourcher *et al.* 1991; Sinton, Donnison and Hastie 1993:117; Leeming 1997:10). Problems with this 'ratio' method relate to variability in the survival of these groups, and because the ratios found in surface waters are likely to be very different from ratios measured in fresh faeces (Leeming *et al.* 1996:2894).

Recent research has shown that one class of biomarkers, the faecal sterols, can be used to accurately trace and identify the source of faecal pollution. Biomarkers are organic compounds that have maintained sufficient structural integrity for their source to be recognised (Leeming *et al.* 1996:2893). However, while faecal sterols have long been recognised as a measure of human faecal pollution, they have not been widely embraced as sanitary indicators. Reasons for this include the presence of sterols in animal products such as eggs, milk, lard and wool grease (Sinton, Finlay and Hannah 1998:336). Also, the presence of sterols is not indicative of health risk (Leeming 1997:10).

Recent research, however, has investigated differences in the neutral lipid composition and bacterial indicator profiles of faecal matter from a range of common animals. The most commonly found faecal sterol, the C_{27} compound coprostonal (5β C_{27}-cholestan-3β-ol), is produced in the intestines of humans by the microbial hydrogenation of cholesterol (Leeming 1997:10; Sinton, Finlay and Hannah 1998:336). Herbivores also have coprostanol in their faeces, but the dominant sterol in these faeces is the C_{29} homologue of coprostanol, 24-ethylocoprostanol (24-ethyl-5β(H)-cholestan-3β-ol). For a variety of reasons these faecal sterols are source specific. This source specificity is related to a combination of sterol intake, metabolic production of sterols and the biota resident within the animal's digestive tract (Leeming *et al.* 1996:2893). As different animals (omnivorous, carnivorous and herbivorous) eat different foods their diets contain different sterols in different amounts. Each group therefore provides a distinctive and unique profile when analysed.

This means that the sterol fingerprints of the faeces of humans and other animals are sufficiently distinctive to be of diagnostic value in determining whether faecal pollution in water samples is of human or animal origin (Leeming *et al.* 1996; Sinton, Finlay and Hannah 1998:337). For example, it was found that differences in the ratio of C_{27} compound coprostanol to the C_{29} compound 24-ethylcoprostanol in human and herbivore faeces could be used to determine the relative contribution of these two sources in cases of faecal pollution (Leeming 1997:10).

The use of 'sterol fingerprinting' in wilderness areas would be a great advantage for management. It would facilitate a better understanding of the effectiveness of current disposal methods of human faecal matter and its impact on water quality and public health. The use of faecal sterols also eliminates the need for spatial and temporal replication which is necessary when using the traditional indicator method.

6.4 Method for the Investigation of Faecal Sterols

6.4.1 Sampling

Sterol analysis was conducted at Douglas Creek on 19 March 1998. Transportation of the equipment required for the analysis of faecal sterols was done with the assistance of a helicopter. Two sites only were sampled due to time constraints. A reference site, located upstream from any infrastructure and camping was tested (DC-1). The other site was the main drinking water collection point for Pelion Plains (DC-3) (see Figure 4.2). Assay procedure began with *in situ* water filtration of the sample (20 litres in a 25 litre container) through a 0.45 µm membrane filter. The water sample was collected with a two litre container which was rinsed several times at each site to prevent contamination. The 20 litre sample consisted of water collected from a number of areas around the site with the two litre container. This was done to increase the representativeness of the water collected for sampling at each site.

As time was limited in the field, the water container was pressurised to increase flow through the filter. This was done successfully with the aid of a foot-operated pump. The container was flushed with ethanol and rinsed between samples. Filters were stored in aluminum foil placed on ice packs for transport, then stored in a freezer and delivered to the Commonwealth Scientific and Industrial Research Organisation (CSIRO) laboratory in Hobart for quantitative extraction of the collected sediment on the filters.

6.4.2 Sampling Conditions

The conditions at Douglas Creek on 19 March 1998 were clear and sunny. No rain fell in the catchment on that day, and it is likely that minimal rain fell for approximately 12 days preceding sampling. Rainfall data are presented in Appendix 1.

6.4.3 Results

Sterol concentrations were only just detectable but not quantifiable. What was evident indicated a bias for C_{29} (5β-stanols) rather than C_{27} sterols, indicating that faecal pollution in this instance was herbivorous in origin (pers. comm. Leeming 1998, and as discussed in section 6.3).

6.4.3.1 ANALYSIS OF FAECAL STEROLS

Total lipid sterols were obtained following alkaline saponification of an aliquot (10 per cent) of the total lipids. Products were extracted iinto hexane.$CCCI_3$ (4/1:v/v) and stored at -20°C. Sterols were converted to their corresponding trimethylsily ethers by treatment with bis(trimethylsily)trifluoroacetamide (50 µL 60°C, 60 minutes) (Leeming, Nichols and Nespolo 1994:7).

6.4.4 DISCUSSION

Sampling occurred during a period of very low (or no) rainfall and therefore minimal amounts of particulate matter were suspended in the creek at the time of sampling. It is also likely that no faecal matter had recently washed into Douglas Creek due to lack of rainfall. As faecal sterols bind strongly to particulate matter in the environment, sampling during wet weather would provide a clearer indication of the source and levels of contamination occurring at Douglas Creek (Leeming 1998; Sinton, Finlay and Hannah 1998:337). The levels of Faecal coliforms and streptococci found in the microbiological analysis for this sample event, 19 March 1998, were also low (see Chapter 5, section 5.4.1 and 5.4.2).

As faecal sterols are able to indicate the source of contamination, their use would greatly enhance the management of wilderness areas. Faecal sterol assessment would also greatly improve knowledge relating to human activities and their associated impacts.

While transportation of the equipment (for example, a filter, filter papers, hoses, water containers and chilling agents) required for sampling faecal sterols was in this instance done with the assistance of a helicopter, it is not an unreasonable weight for effective and easy use in a remote location. The equipment could easily be transported in a few backpacks. The only limiting factor would be the ability to keep the filters chilled. This is, however, not difficult as the filters are very small and lightweight compared to the water required for the traditional indicator method. If sampling were undertaken to coincide with a rain event this would ensure that meaningful data are recorded.

6.5 MACROINVERTEBRATES

Neither of the assessment procedures discussed above (the traditional indicator method and faecal sterols) reveals any information on the impact of faecal contamination on organisms that occur naturally in aquatic ecosystems. This is significant as direct biological assessments of the health of lotic communities may offer vital information about the impact of pollution. Aquatic organisms are very sensitive indicators of pollution as they integrate environmental conditions over time. They may also demonstrate the effects of multiple stresses (Metcalfe-Smith 1996:17). Biological investigations may also be of extreme value in wilderness environments as they can function as an early warning device by detecting intermittent pollution and subtle disruptions that may be missed by conventional methods (Meybeck *et al.* 1996:9). Aquatic insect communities are also valuable indicators of general environmental quality as they are responsive to many types of catchment disturbance, particularly those introduced by humans (Dean and Cartwright 1992:73). Aquatic organisms, therefore, can be very good indicators of pollution, and may be used to identify impacts not recognised in traditional methods of faecal contamination.

It is impractical to conduct bio-assessments on entire aquatic ecosystems, so work generally occurs on a particular component (such as fish, algae or invertebrates). As macroinvertebrates are present in most aquatic habitats, especially flowing water systems, and are abundant and relatively easy and inexpensive to collect, they are often used for environmental assessments. Macroinvertebrates are also sensitive to pollution, are capable of a graded response with various types reacting quickly to disruption, and they have life spans long enough to provide a record of environmental quality. Macroinvertebrate communities are also very heterogeneous, with numerous phyla and trophic levels represented. The probability that at least some of these organisms will react to a particular change in environmental conditions is, therefore, considered to be high (Metcalfe-Smith 1996:17).

The use of macroinvertebrate bioassessment, however, has three major disadvantages. Firstly, because they respond to minor environmental changes, it is difficult to discriminate between effects of pollution and other environmental factors. Secondly, macroinvertebrates have complex life histories, so care must be taken to sample in a variety of seasons. Thirdly, the spatial heterogeneity of macroinvertebrate species is high so considerable replication is required for accurate assessment (Metcalfe-Smith 1996:17-18).

6.5.1 METHOD OF MACROINVERTEBRATE INVESTIGATION

6.5.1.1 Site Selection

Macroinvertebrate samples were collected from four sites along Douglas Creek where it flows through Pelion Plains (Figure 4.2). These sites correspond to sites DC-1, DC-3, DC-4 and DC-5, which were used for the microbiological sampling (see section 4.4). These sites were selected as both DC-1 and DC-3 have similar vegetation types, dominated by riparian rainforest species, and DC-4 and DC-5 are both found in the buttongrass dominated flora where Douglas Creek crosses Pelion Plains. As DC-1 was upstream from any infrastructure associated with human activity it represents an undisturbed reference site. DC-3 was the main drinking water collection point directly east of New Pelion Hut. DC-4 was at the track junction of the Arm River and Mt Oakleigh tracks. The location of Site DC-5 for the macroinvertebrate sampling was approximately 20 metres upstream from the site used for microbiological indicator collection. This was because the site for the collection of microbiological indicators was too deep for the safe collection of macroinvertebrates.

6.5.1.2 Sampling

Sampling of macroinvertebrates occurred in the afternoon of 26 May and the morning of 27 May 1998. Aquatic samples were collected using the kick sampling technique (Davies 1994). The substratum was vigorously disturbed by foot while a mesh dip net (standard 250μm mesh pore size) was held downstream with its mouth facing upstream (the net was washed prior to and after each sampling). Boulders that were too heavy to turn were rubbed by hand if necessary. This process was applied continuously working upstream covering a total distance of ten metres. Three replications of riffle (area with steep, broken water with a rapid current) and flat sections of the creek at each site were sampled to allow for the comparison of macroinvertebrate assemblage composition within and between habitats. For the riffle sections, an attempt was made to sample both the fastest and slowest flowing sections (Davies 1994). Material from macrophytes and wood debris was avoided.

Samples were placed in an air-tight bag and labelled for later laboratory-picking. Upon return to the university, approximately 8 hours later, each sample was drained of excess water, bottled in alcohol and labelled. The samples were then returned to the plastic tray and each sample picked for a total of five minutes using forceps and a pipette. Picked macroinvertebrates were then placed into vials containing ethanol. An attempt was made to pick samples from as full a list of taxa as possible by avoiding the biased selection of large or colourful taxa (Davies 1994).

6.5.1.3 Macroinvertebrate Identification

The contents of vials containing specimens were placed under a stereo microscope. All organisms were identified to family level, counted and recorded (a full list of taxa is presented in Appendix 3).

6.5.1.4 Data Collation and Analysis

A number of different techniques were used to analyse the invertebrates and their distribution. All macroinvertebrate data were entered and stored in an Excel® spreadsheet format. Average family richness was calculated in Excel®.

Data were transferred to SPSS® for Family analysis. The data were subjected to ANOVA (analysis of variance) and post-hoc tests (Dunnett's T3 test - assumed unequal variance).

Sites were ordinated in the PATN program. Multidimensional scaling was used to summarise the relationship between sites on the basis of their invertebrate fauna. Data were entered as counts and the Bray-Curtis index was used to generate an association matrix. Three dimensions gave a satisfactory stress level of 0.1156.

Correlations between the ordination axes and macroinvertebrate taxa were sought using the principal axis correlation method. The Monte Carlo technique was then used to determine the significance of these correlations.

6.5.1.5 Limitations

Due to time and financial restrictions of undertaking field work in a remote area, a one-off, snapshot macroinvertebrate survey was undertaken. While the usefulness of only undertaking one sampling event is limited, it does provide important baseline ecological information. This information, while not comprehensive, can be used for comparative purposes at a later date. Consequently, it is not possible from this sample to fully assess variability within and between sites at Douglas Creek. Any conclusions drawn from a temporally limited investigation will have significant repercussions and therefore care must be taken (Boulton and Lake 1992:100).

As macroinvertebrates distributions are commonly clumped, fitting a negative binomial distribution, sampling design must account for habitat-related patchy distributions (Cummins 1996:77). All information gained during this macroinvertebrate investigation is likely to be relative rather than absolute, and replicate sampling during different seasons is required to gain an indication of accurate abundance. The status of individual taxa would be likely to change if sampling intensity was also increased (Dean and Cartwright 1992:74).

6.5.2 RESULTS

A total of 1 015 specimens were collected from the four sites distributed along Douglas Creek. These represented six orders and 27 families of macroinvertebrates (see Appendix 3 for a full list of taxa).

The macroinvertebrate data was subjected to a number of tests in an attempt to identify any significant difference between sites. Due to the spatial distribution of the sites along Douglas Creek, observed zonation patterns in the fauna may provide information of any influence of human activity. However the results may also represent natural zonation patterns. By averaging the species in each replicate at each site it is possible to obtain the average Family richness for each site (see Table 6.1).

Table 6.1 Average Family Richness at each Sampling Site at Douglas Creek

Site	Average Family Richness
DC-1	7.3
DC-3	8.0
DC-4	5.2
DC-5	7.3

ANOVA for significance of species richness are presented in Table 6.2.

Table 6.2 The Influence of Site and Substrate and their Interaction on Richness (ANOVA followed by a post-hoc Dunnett's T3 Test).

Site	$F_3 = 3.379$, $P = 0.044$	*
Substrate	$F_3 = 0.015$, $P = 0.93$	ns
Sub * Site	$F_3 = 1.492$, $P = 0.255$	ns

ns - not significant
* < 0.05

Analysis of variance was used to test if site, substrate and the site and substrate interaction influenced richness. Only site was found to be significant in affecting richness. A post-hoc test detected that mean species richness differed between sites DC-3 and DC-4.

A t-test showed that there is no significant difference between riffle (r) and flat (f) (the substrates) habitat types at Douglas Creek (Table 6.3).

Table 6.3 t-test Determining Difference between Riffle and Flat

Substrate	Richness	Standard Error	$t_{2, 352}$
Riffle	3.07	0.51	0.61 (n.s)
Flat	2.66	0.47	

To further analyse the influence of site, the responses of potentially sensitive families were examined using a range ANOVA (see Table 6.4).

Table 6.4 Results of ANOVA and Post-hoc Dunnett's T3 tests

Family	ANOVA	Post-hoc Dunnett's T3 test
Leptophlebiidae	$F_{3,16} = 3.927$, $P = 0.028$ *	DC-5 and DC-3 *
Baetidae	$F_{3,16} = 11.116$, $P = < 0.001$ ***	DC-1 different to DC-3 and DC- 4
Hydrochidae	$F_{3,16} = 4.802$, $P = 0.072$	
Simuliidae	$F_{3,16} = 0.682$, $P = 0.576$	
Gripopterygidae	$F_{3,16} = 1.287$, $P = 0.313$	
Eusthenidae	$F_{3,16} = 3.032$, $P = 0.060$	
Chironomidae	$F_{3,16} = 1.905$, $P = 0.170$	

ns - not significant
*** < 0.001
* < 0.05

The output from the multidimensional scaling analysis (ordination) is shown in (Figure 6.1). An extreme outlier in site DC-4 was removed as it was defined by absence of most species.

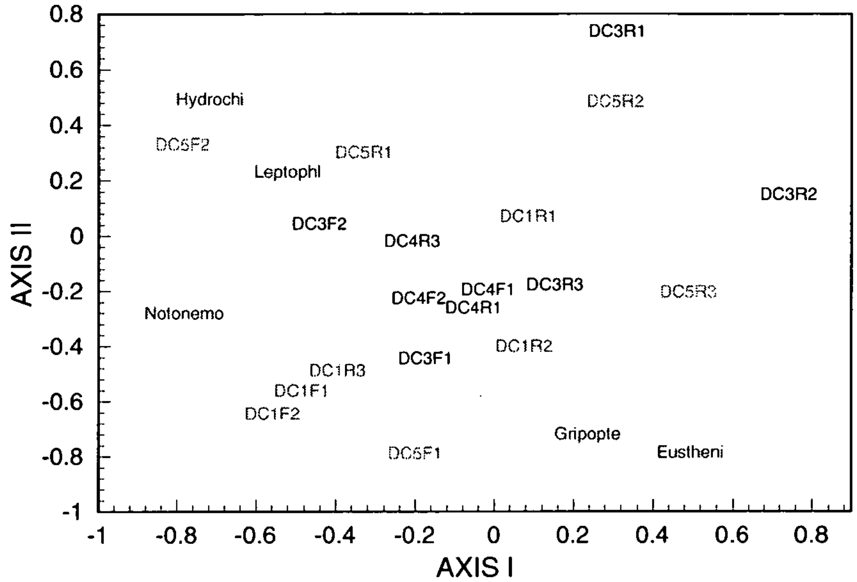

Figure 6.1 Ordination of Douglas Creek Sites Based on Untransformed Data with Significantly ($p < 0.05$) Correlated Taxa Fitted in the Same Ordination Space

Ordination was used to examine the relationship between the sites based upon their fauna. Relationship is a function of distance between sites in the ordination, for example, sites that plot close together share similar fauna.

Most taxa were not significantly correlated with the ordination. However six taxa were correlated; Leptophlebiidae (mayflies), Gripopterygidae (stoneflies), Hydrochidae (beetles), Eusthenidae (stoneflies), Notonemouridae (stoneflies), and Baetidae (mayflies) (Table 6.5).

Table 6.5 Correlation Coefficients and their Significance Value from Ordination Using all Taxa Untransformed (Raw) Data Set

Taxon	Correlation Coefficient	Significance
Leptophlebiidae	0.869	**
Gripopterygidae	0.744	**
Hydrochidae	0.727	**
Eusthenidae	0.698	*
Notonemouridae	0.618	*
Baetidae	0.588	*
Nematocera	0.516	ns
Athericidae	0.494	ns
Tipulidae	0.493	ns
Elmidae	0.473	ns
Oeconesidae	0.448	ns
Calocidae	0.410	ns
Platyhelmidae	0.402	ns
Leptoceridae	0.398	ns
Austroperlidae	0.380	ns
Dytiscidae	0.379	ns
Philorheithidae	0.333	ns
Stratiomyidae	0.323	ns
Oniscigastridae	0.313	ns
Chironomidae	0.299	ns
Hydrobiosidae	0.290	ns
Conoesucidae	0.280	ns
Calamoceratidae	0.251	ns
Elmidae Adult	0.242	ns
Blephariceridae	0.223	ns
Empididae	0.223	ns
Simuliidae	0.139	ns

ns = not significant
* < 0.05
** < 0.01

6.5.3 Discussion

Each macroinvertebrate community has particular requirements with respect to physical, chemical and biological conditions of its habitat. Changes in these conditions can result in reduction in species numbers, a change in species dominance or total loss of sensitive species by death or migration. While it is not possible from the results to gain a clear understanding of the presence or absence of impacts at Douglas Creek it is possible to highlight that more detail sampling is required.

The results from the macroinvertebrate survey indicate that substrate was not an important factor in family richness at these sites (see Table 6.2). Therefore for future sampling of these sites, differentiation of substrate need not be an important consideration. Future sampling would also benefit from the use of species identification. Site DC-4 in the ordination appears clumped indicating a degree of difference from the other sites (see Figure 6.1). Likewise, samples from site DC-1 also appears relatively clumped which would support the hypothesis. It is, however, not possible to make any firm conclusion relating to impacts from these data as results demonstrate a function of high variability as the data are not normalised. This is due to there being only three replicates. Further sampling is therefore required to make an accurate assessment of the extent of any impact.

6.5.4 Conclusions

The use of faecal sterols as a biomarker facilitates not only identification of contamination levels, but also the ability to locate the source of contamination. It is argued that effective management of wilderness areas would, therefore, be enhanced through the use of faecal sterols. Sampling should preferably coincide with a rain event to allow the source of contamination to be more easily identified.

Because faecal sterols are source specific, the effectiveness of current human waste management practice would also be clearer. This information would be of great assistance to managers who generally have no measure of human waste policy effectiveness other than anecdotal information. For example, this information would be of great assistance in differentiating the effectiveness of different toilet systems and waste disposal of practices. As contamination levels could be compared, information of this nature could provide knowledge on safe distances between toilets or burial sites and watercourses.

Further macroinvertebrate sampling is required to fully assess any ecological indication of impact. This investigation has, however, classified sites on the basis of similarity which is useful to see how the sites relate. It has also been possible to recognise impacted sites. The application of this method is useful for management purposes as it provides an indication of long term impacts which may not be detected by other methods.

CHAPTER 7

Conclusions and Research Recommendations

7.1 CONCLUSIONS

This thesis investigated some of the major impacts associated with human wastes within wilderness environments. A case study, focusing on the Pelion Plains region of the Overland Track in Tasmania, was employed to provide information relating to a heavily used wilderness area. The case study was also utilised to evaluate the traditional method for assessing one of the major impacts associated with human wastes in wilderness areas – faecal contamination of surface water. Alternative methods were also trialled.

This investigation is significant as it revealed faecal contamination in the surface waters used for drinking in a wilderness area. In all sample events, levels of contamination exceeded the Australian Standards for drinking water quality. The implications from a public health perspective are important as minimal warning is currently provided to advise visitors of the risk associated with consuming untreated water in Tasmanian wilderness areas. Assumptions commonly made that the water in these areas is 'pristine' are misleading and may lead to the transmission of enteric disease.

While some level of faecal contamination of surface water was expected (due to the presence of animals in the catchment) the hypothesis of this thesis was that human wastes produce a detectable impact at the Pelion Plains region. It was therefore necessary to not only identify contamination, but also determine its source(s).

While the traditional indicator method was used, as it is able to detect contamination, this method fails to directly specify the source(s) of contamination. Source identification, however, is often imperative to problem resolution and is generally inferred from the spatial distribution of contamination and its relationship to variables such as human activity and associated toilet infrastructure. This method requires considerable replication and is costly. This method also requires the collection of large volumes of water to be transported to a laboratory for analysis within a restricted time frame. The combination of these factors makes the traditional indicator method difficult and costly to use in remote areas.

The results from this investigation indicate that it is likely that some human faecal contamination is occurring in the surface waters used for drinking at Pelion Plains. It was not possible, however, due to the financial and time limitations imposed on an investigation of this nature to extensively and repeatedly investigate traditional indicators at Pelion Plains. The discovery of human waste contamination in surface waters used for drinking is significant as it suggests that current management is inadequate as it fails to contain wastes and the potentially harmful pathogens.

Due to a number of difficulties encountered with the traditional indicator method alternative methods were trialled. A method that uses a class of biomarkers, the faecal sterols, was employed in an attempt to accurately trace and identify the source(s) of faecal pollution. Due to a lack of (antecedent) rain at the time of sampling it was not possible to gain an accurate indication of the source(s) of contamination at Pelion Plains. However, the ability of this method to not only detect contamination, but also to accurately identify its source(s) makes it suitable for use in wilderness environments. It is also easily adaptable for use in remote environments.

A limited benthic macroinvertebrate survey was also trialled as a method in this investigation to identify any impact associated with human wastes. This type of ecological survey is useful because it provides information on the overall health of the aquatic ecosystem. A macroinvertebrate analysis may also reveal past or cumulative effects not detected by the other 'snapshot' sampling methods. The macroinvertebrate analysis was primarily undertaken to provide baseline data for future consideration. Information of this nature was found to be lacking for wilderness areas in general although it is vital for detecting any ecosystem changes.

A further aim of this thesis was to highlight areas requiring attention for the management of human waste impacts, with particular emphasis on public health. A number of significant issues were revealed.

None of the available methods are able to predict the risk of disease to an individual following consumption of contaminated water. The fact that contamination is occurring, coupled with the failure of indicators to predict risk, underlines the prime importance of maintaining effective barriers to prevent faecal material entering the water supply. The problem of exactly how to monitor bacteriological water quality in wilderness areas therefore remains as a major research issue.

The reduction of animal contact with human wastes is urgently required in order to prevent the spread of zoonotic diseases, such as Giardiasis in wilderness areas. In particular the importance of reducing animal contact relates to the potentially large number of zoonotic diseases that may occur in wilderness areas, as animals are currently able to consume large quantities human faecal matter. This point also relates to the commonly perceived view that human faeces constitute a greater health risk than animal faeces, however, epidemiological evidence is severely lacking to support this.

Statements made to the public regarding health warnings must be based on the poorest quality water that could possibly be encountered. The implications relating to the issuing or not issuing health warnings require urgent management attention.

It also emerged through this thesis that a multidisciplinary approach to the management of issues and impacts associated with human wastes in wilderness areas is urgently required. Principally, this is due to the diversity of factors requiring consideration for the effective management of human induced impacts in wilderness environments.

Another major finding of this investigation was that management decisions are often based on and assessed in aesthetic terms. This focus on tangible aspects implies that many issues, which are not immediately visible, may be overlooked. This thesis has focused on and explored one such issue - the presence of non-visible pathogenic contaminants in surface waters. Failure to adequately address this issue through research and the implementation of management strategies has the potential to (and in some areas already has) lead to the loss of one of the pleasures associated with wilderness areas – drinking directly from mountain steams.

Human wastes in wilderness areas are currently creating a number of impacts. The severity of impacts if often underestimated due to a lack of information and understanding. This study represents the first major detailed investigation of this nature in the Tasmanian wilderness environment. This is significant as the current paucity of relevant information concerned with human wastes and their impacts represents a major impediment to effective management as the development of effective management strategies is clearly dependent on the quality of available information.

7.2 RESEARCH RECOMMENDATIONS

This investigation elicits many questions and reveals enormous scope for areas requiring further research. It is suggested that research in the areas discussed below may be of particular benefit in managing human waste disposal in wilderness areas, and in minimising the impact that human wastes can have on water quality.

Perhaps the most urgent issue that emerged during this research is the need to define an adequate indicator for water quality in wilderness areas. This requires the formation of a baseline data set of specific areas and situations that recognised the unique qualities and influences. Further testing to assess the applicability of faecal sterols for use as indicators in wilderness environments is also highly recommended.

There also exists an urgent need for epidemiological investigation of users of wilderness areas. Such studies are needed to determine the implication of faecal contamination (and associated diseases such as Giardiasis) of waters used for drinking and recreation in wilderness areas.

The development of improved toilet technology for areas of high-use is also an area requiring urgent research attention. The development of toilet technology that prevents faecal contamination would greatly reduce the impact associated with human wastes in wilderness areas.

Ideally, a new toilet system would effectively eliminate or treat liquid effluent, reduce odours, and minimise animal contact with associated pathogens (and thereby limit the transmission of zoonotic diseases). The development of technology that could easily be adapted to operate in conjunction with currently operating toilet systems and reduce their impact is also suggested as an area requiring further research and development. An example would be to develop an effective evaporation device for the removal of toilet effluent.

Research into alternative waste management practices, such as a personal *carry-out* system, could also help to eliminate many of the impacts associated with human waste disposal (particularly in low-use areas). Further research of social issues influencing individual human waste disposal practice may provide insights necessary to overcome problems of user compliance.

Further research into techniques aimed at reducing impacts of human wastes buried in individual burial-holes is also urgently needed. In particular, studies could focus on optimal distances from water and depths of holes, the effect of stirring wastes, and on methods which may reduce animal consumption and therefore the transmission of zoonotic disease.

Finally, it is recommended that further research into issues specific to female users of wilderness environments be undertaken and findings be incorporated into waste management practices and educational literature.

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APPENDIXES

Appendix I: Rainfall Data for Cradle Valley and Lake St Clair

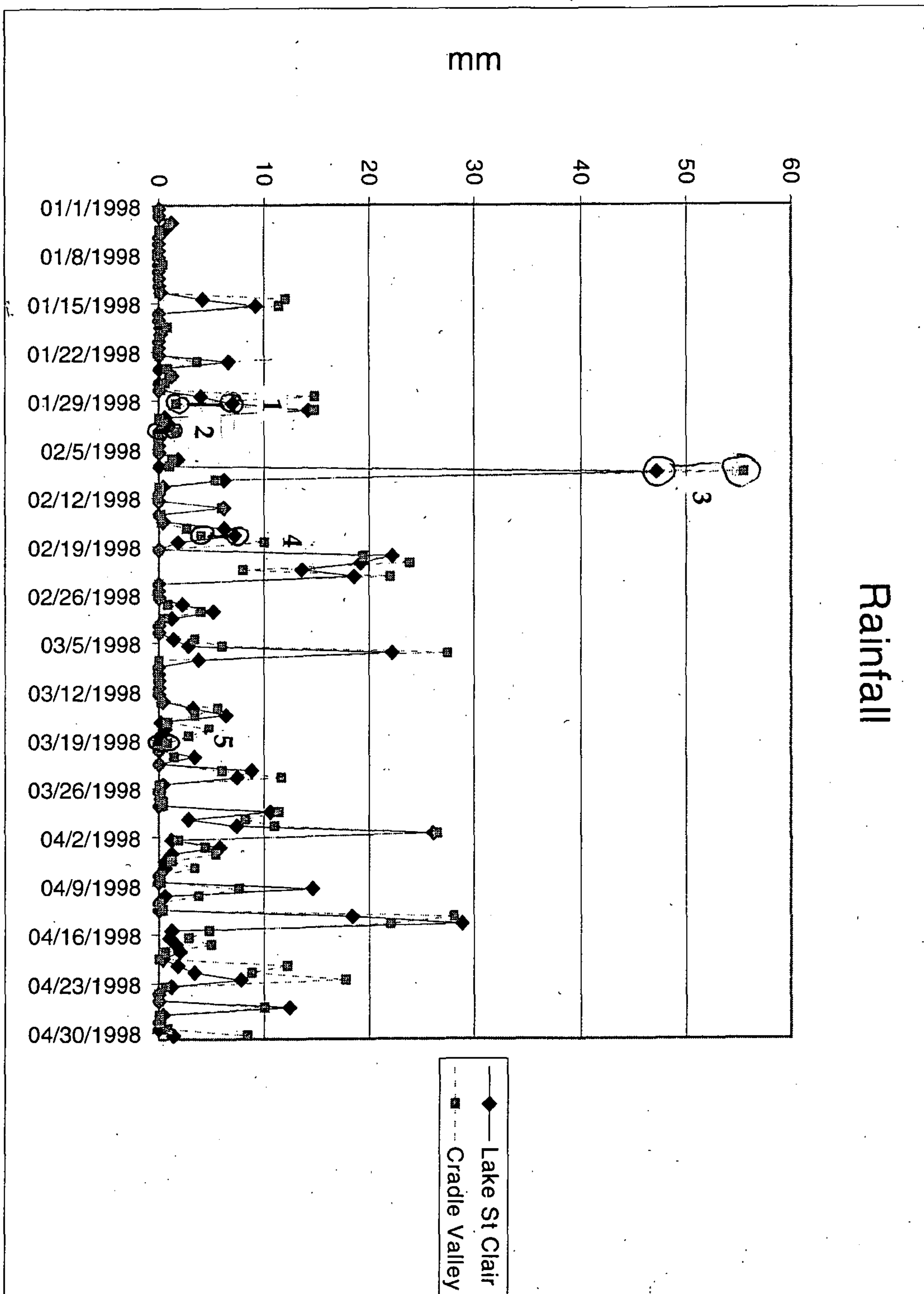

Figure 1: Rainfall Data for Cradle Valley and Lake St Clair

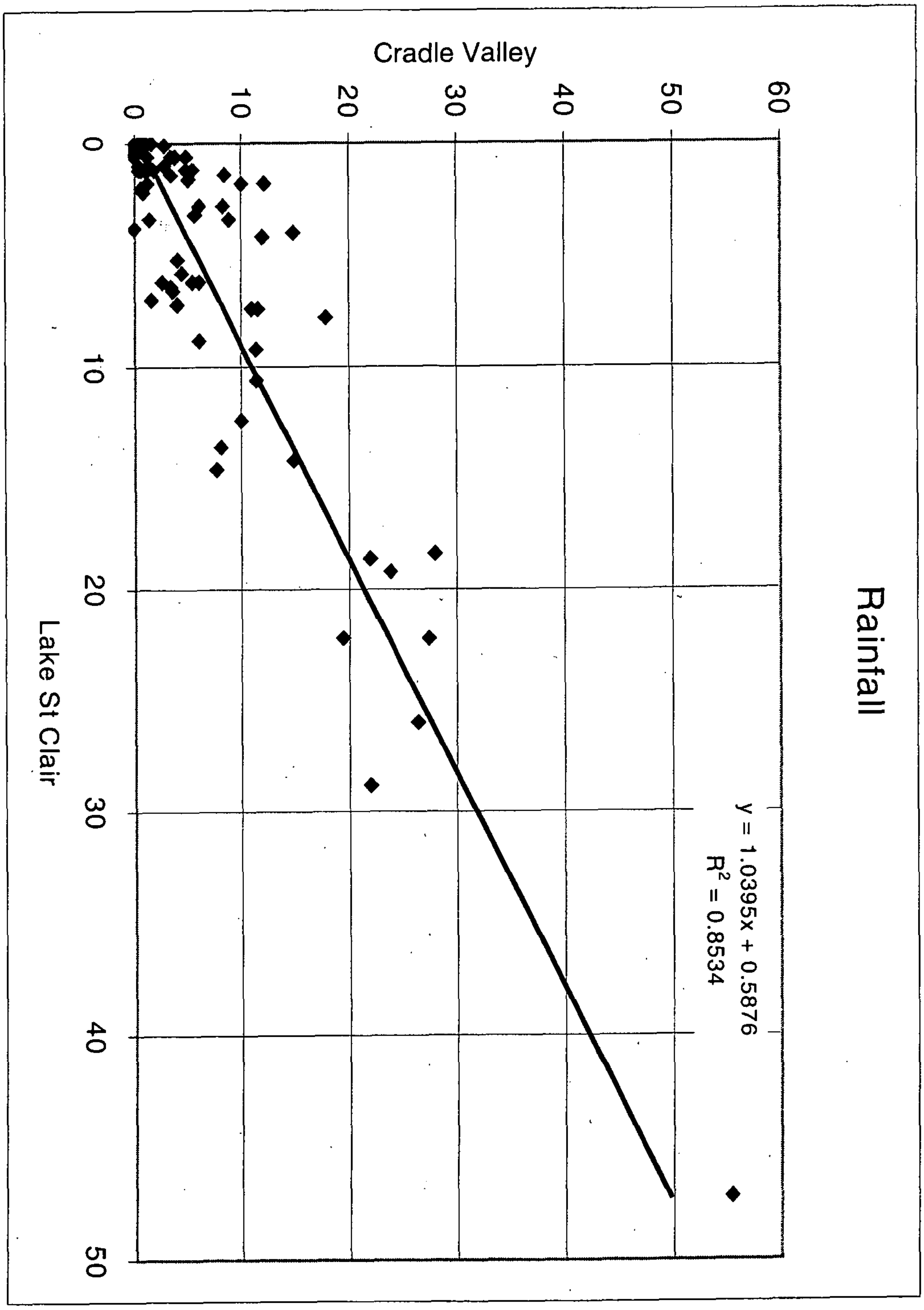

Figure 2: Correlation of Rainfall Data for Cradle Valley and Lake St Clair

APPENDIX 2: MICROBIOLOGICAL RESULTS

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MICROBIOLOGICAL RESULTS FORM Water (1998)

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Report No. W36/98
Page: 1 of 2
Date report issued: 2/2/98 (interim), 9/2/98 (interim), 12/2/98(interim), 23/3/98(final)

Sample No.	Lab No.	Sample Type	Sample Site	Sample Use	Date & Time Collected	Date Sub-mitted	Date of Tests	Tests* Required	Results FC/100ml	Results FS/100ml
DC-1	W1/83	Water	Douglas Creek DC-1	Ambient	29/1/98, 1300	30/1/98	30/1/98	FC, FS	80(est)	100(est)
DC-2	W1/84	"	DC-2	"	" 1325	"	"	"	91	160
DC-3	W1/85	"	DC-3	"	" 1345	"	"	"	280	420
DC-4	W1/86	"	DC-4	"	" 1355	"	"	"	260	220
DC-5	W1/87	"	DC-5	"	" 1315	"	"	"	370	110(est)
DC-1	W2/4	"	DC-1	"	2/2/98, 1240	3/2/98	3/2/98	"	24	22
DC-2	W2/5	"	DC-2	"	"	"	"	"	42	41
DC-3	W2/6	"	DC-3	"	" 1230	"	"	"	32	140
DC-4	W2/7	"	DC-4	"	"	"	"	"	47	54
DC-5	W2/8	"	DC-5	"	" 1255	"	"	"	59	18
DC-1	W2/32	"	DC-1	"	8/2/98, 2030	9/2/98	9/2/98	"	280	25
DC-2	W2/33	"	DC-2	"	" 2050	"	"	"	370	120
DC-3	W2/34	"	DC-3	"	9/2/98, 0700	"	"	"	70	75
DC-4	W2/35	"	DC-4	"	" 0600	"	"	"	180	60
DC-5	W2/36	"	DC-5	"	" 0630	"	"	"	410	57

* tests were performed on samples as received
FC=Faecal Coliforms FS = Faecal Streptococci est = estimate

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Sample No.	Lab No.	Sample Type	Sample Site	Sample Use	Date & Time Collected	Date Submitted	Date of Tests	Tests* Required	Results FC/100ml	Results FS/100ml
DC-1	W1/83	Water	Douglas Creek DC-1	Ambient	29/1/98, 1300	30/1/98	30/1/98	FC, FS	80(est)	100(est)
DC-2	W1/84	“	DC-2	“	“ 1325	“	“	“	91	160
DC-3	W1/85	“	DC-3	“	“ 1345	“	“	“	280	420
DC-4	W1/86	“	DC-4	“	“ 1355	“	“	“	260	220
DC-5	W1/87	“	DC-5	“	“ 1315	“	“	“	370	110(est)
DC-1	W2/4	“	DC-1	“	2/2/98, 1240	3/2/98	3/2/98	“	24	22
DC-2	W2/5	“	DC-2	“	“	“	“	“	42	41
DC-3	W2/6	“	DC-3	“	“ 1230	“	“	“	32	140
DC-4	W2/7	“	DC-4	“	“	“	“	“	47	54
DC-5	W2/8	“	DC-5	“	“ 1255	“	“	“	59	18
DC-1	W2/32	“	DC-1	“	8/2/98, 2030	9/2/98	9/2/98	“	280	25
DC-2	W2/33	“	DC-2	“	“ 2050	“	“	“	370	120
DC-3	W2/34	“	DC-3	“	9/2/98, 0700	“	“	“	70	75
DC-4	W2/35	“	DC-4	“	“ 0600	“	“	“	180	60
DC-5	W2/36	“	DC-5	“	“ 0630	“	“	“	410	57

* tests were performed on samples as received
FC=Faecal Coliforms FS = Faecal Streptococci est = estimate

APPENDIX 3: FULL TAXA LIST FOR DOUGLAS CREEK

CLASS	ORDER	FAMILY	RI	R2	R3	F1	F2	F3
DC-1	Coleoptera	Hydrochidae	1	0	1	1	1	9
DC-1	Ephemeroptera	Baetidae	7	11	14	16	12	4
DC-1	Ephemeroptera	Leptophlebiidae	15	10	23	15	26	22
DC-1	Plecoptera	Austroperlidae	1	3	1	2	2	0
DC-1	Plecoptera	Eusthenidae	8	12	3	3	1	0
DC-1	Plecoptera	Gripopterygidae	25	13	5	0	0	0
DC-1	Plecoptera	Notonemouridae	2	0	0	1	2	7
DC-1	Trichoptera	Calamoceratidae	0	0	0	0	0	1
DC-1	Trichoptera	Hydrobiosidae	0	0	0	0	1	0
DC-1	Trichoptera	Oeconesidae	0	1	0	0	0	0
DC-1	Diptera	Chironomidae	2	0	1	0	0	1
DC-1	Diptera	Simuliidae	1	0	0	0	0	0
DC-1	Diptera	Tipulidae	0	0	1	1	0	1
DC-3	Coleoptera	Elmidae/adult	0	1	0	0	0	0
DC-3	Coleoptera	Hydrochidae	0	1	0	11	16	4
DC-3	Ephemeroptera	Baetidae	0	0	4	1	1	1
DC-3	Ephemeroptera	Leptophlebiidae	43	12	35	40	29	28
DC-3	Ephemeroptera	Oniscigastridae	3	0	0	0	0	0
DC-3	Plecoptera	Austroperlidae	1	3	1	1	2	1
DC-3	Plecoptera	Eusthenidae	1	2	4	0	0	0
DC-3	Plecoptera	Gripopterygidae	23	0	25	3	0	0
DC-3	Plecoptera	Notonemouridae	0	0	0	4	10	1
DC-3	Trichoptera	Calamoceratidae	0	0	0	0	0	1
DC-3	Trichoptera	Calocidae	0	0	0	0	11	1
DC-3	Trichoptera	Hydrobiosidae	2	3	0	0	0	0
DC-3	Trichoptera	Leptoceridae	1	0	0	0	0	0
DC-3	Trichoptera	Philorheithidae	0	1	0	0	0	0
DC-3	Diptera	Simuliidae	10	0	0	0	1	0
DC-3	Diptera	Tipulidae	1	0	1	0	4	1
DC-3	Diptera pupae	Nematocera pupae	3	0	1	1	0	0
DC-3	Tricladida	Platyhelmidae	0	0	1	0	0	0
DC-4	Coleoptera	Dytiscidae/larva	0	0	0	1	0	0
DC-4	Coleoptera	Elmidae/adult	1	0	0	0	0	0
DC-4	Coleoptera	Hydrochidae	12	0	12	7	18	5
DC-4	Ephemeroptera	Baetidae	0	0	0	1	1	2
DC-4	Ephemeroptera	Leptophlebiidae	17	0	31	6	30	18
DC-4	Plecoptera	Austroperlidae	0	0	0	2	3	0
DC-4	Plecoptera	Gripopterygidae	2	0	13	0	0	0
DC-4	Plecoptera	Notonemouridae	0	0	0	1	0	0
DC-4	Trichoptera	Conoesucidae	0	0	0	1	0	0
DC-4	Trichoptera	Hydrobiosidae	0	0	1	0	0	1
DC-4	Diptera	Athericidae	0	1	0	0	3	0
DC-4	Diptera	Chironomidae	1	0	0	1	1	0
DC-4	Diptera	Simuliidae	2	0	1	0	1	0
DC-5	Coleoptera	Elmidae/larvae	0	6	2	4	1	0
DC-5	Coleoptera	Hydrochidae	1	2	3	1	7	2
DC-5	Ephemeroptera	Baetidae	11	4	0	5	1	1
DC-5	Ephemeroptera	Leptophlebiidae	23	12	10	16	0	5
DC-5	Plecoptera	Austroperlidae	0	1	1	2	0	0
DC-5	Plecoptera	Eusthenidae	1	1	10	0	3	0

DC-5	Plecoptera	Gripopterygidae	5	2	7	0	0	2
DC-5	Plecoptera	Notonemouridae	0	0	0	0	5	2
DC-5	Trichoptera	Conoesucidae	1	0	1	0	0	0
DC-5	Trichoptera	Hydrobiosidae	0	2	0	0	0	0
DC-5	Diptera	Blephariceridae	0	0	0	1	0	0
DC-5	Diptera	Chironomidae	0	0	1	1	1	0
DC-5	Diptera	Empididae	0	0	0	1	0	0
DC-5	Diptera	Simuliidae	1	0	0	2	0	0
DC-5	Diptera	Stratiomyidae	0	1	0	0	0	0

Substrate: R = riffle F = flat